PLANNING AND ENGINEERING DATA
3. FISH FREEZING

Edited by

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ROME, October 1984

ABSTRACT

Fish freezing is one of the methods most used for processing fish and other edible aquatic products. Fish-freezing industry and frozen fish products are very well known on all world markets. A flourishing fish-freezing industry (shrimp, lobster, etc.) in many developing countries was a boom during the last 10 years with wide possibilities for increasing production and export which, in many countries, is the main source of foreign currency.

This document is published for planning, elaboration of feasibility studies, operations of fish processing before freezing, during freezing, storing and transporting of frozen products. This document will provide the industry, especially in developing countries, with a practical up-to-date data of a technical and economic nature. It should be also suitable for use in governmental offices, specialized schools (training courses), etc. Main subjects covered concern raw material and its preparation for freezing, source of cold, processing equipment, packaging material, storage conditions and equipment, management of cold stores, construction of cold stores, transportation, as well as costing and case studies. It also includes diagrams, schemes, figures, tables and numerical data related to the subject.

W/U5724

For bibliographic purposes this document should be cited as follows:

Graham, J. (ed.), Planning and engineering data. 3. Fish freezing. FAO Fish.Circ., (771):126 p. 1984

FAO Fisheries Circular (FAO Fish.Circ.)

A vehicle for distribution of short or ephemeral notes, lists, etc., including provisional versions of documents to be issued later in other series.

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1. INTRODUCTION

1.1 Subject Matter

This document is one of a series providing engineering and other data to facilitate the planning of fish processing and handling operations. It is specifically concerned with the freezing and cold storage of fishery products and it deals mainly with operations and products which are currently widely used and produced. Much of the information, however, can be interpreted or modified to apply to other related applications.

1.2 Aim and Purpose

The document is intended to meet the direct needs of industry and also governments and other official agencies likely to be involved in the planning of freezing and cold-storage installations.

It is hoped that the document will be of particular benefit to developing countries, but since it is intended to be used under widely different conditions it should always be used with caution.

Unqualified information can often do more harm than good, therefore, a clear understanding of the relevant conditions that apply to each situation are essential for detailed planning. Since it is not possible to cover all eventualities, the document can therefore be no more than a guide to good planning.

1.3 Sources of Information

The information in this document is obtained from a number of sources.

Much of it is based on the experience of the authors and their colleagues at the UK's Torry Research Station. Publications of FAO, the International Institute of Refrigeration (IIR) and the American Society of Heating, Refrigeration and Airconditioning Engineers (ASHRAE) have also been a valuable source of information and extensive use has been made of manufacturers' catalogues. Another source has been through direct enquiry to manufacturers, contractors and processors, too many to name individually, but their help was greatly appreciated and is acknowledged.

All costs are based on UK prices for the period 1983-84 and conversion to US dollars was made at the then-current exchange rate of US$ 1.5 = £ 1.

1.4 Related Material

The other FAO documents in this series are:

1. Planning and Engineering Data 1 - Fresh Fish Handling, FAO Fish.Circ.735;
2. Planning and Engineering Data 2 - Fish Canning, under preparation;
3. Planning and Engineering Data 4 - Containers for Fish Handling, under preparation;
4. Planning and Engineering Data 5 - Packages and packaging material for fish products, under preparation.

FAO and other selective documents, which expand on many of the points made in this document and also give other additional, relevant information, are listed in the Literature Consulted on Page 125.

2. RAW MATERIAL

2.1 Fish

All fish are suitable for freezing in one form or another but, in practice, relatively few of the many species available are marketed in this way.

In developing countries freezing and cold storage are mainly used for fish intended for export, since in most of these countries the necessary "cold chain" for marketing frozen fish internally has yet to be developed.

Fish exported from developing countries tends to be the higher priced products since the foreign exchange earned is more beneficial to the home economy than if the products were used for internal consumption. Many types of shellfish, both crustaceans and molluscs, come into this category with shrimp/prawn being by far the most important. Other shellfish such as lobster, crayfish, crab, abalone, scallops and the cephalopods such as squid, octopus and cuttlefish are also in demand as frozen imports.

There is also an active international trade in some of the higher priced and more popular finfish species such as cod, haddock, pollock, pomfret, snapper, salmon and sole, both as whole fish and, for some of the species, processed or semi-processed fish products.

Tuna and other species which are caught seasonally are also in demand as frozen products in order to provide continuity of supplies throughout the year at processing establishments.

The above opportunities for the production and marketing of frozen fish products already exist for most countries and as internal cold chains develop, marketing opportunities for a wider range of frozen fish products will result.

In addition to their preference for certain species only, markets for frozen fish demand that other standards have to be met, with quality and size grading being two of the most important.

Quality standards may be imposed by the customer, by authoritative codes of practice or regulations in the country of origin or consignment or initially by the producer. Fish quality may be measured in many ways and standards changed from time to time, therefore, it is imperative that a full investigation should be made of the current requirements and whether they can be met before a freezing operation is initiated. More information on this aspect is given in 5.2.3 and in a number of the references given in Section 8.

Size grading standards are more uniform and more widely applied than other quality standards, probably because they are more readily defined, attained in commercial practice and checked by the customer. Size grading can be either by weight, measurement of fish length or other dimension or by a count of units in a standard package or weight.

Examples of grades applied to frozen shellfish products are given in Tables 1 and 2. It can be seen from these tables that market grades do not necessarily follow the grading recommendations set down by international codes, therefore, potential customers should always be consulted on this subject at an early stage of planning to ascertain the standards they are likely to require.

Table 1

Size grading of frozen shrimp

Headless shrimp Japanese market (count/kg)	Peeled and deveined shrimp US market (count/kg)	Codex recommendations[a/] for all shrimp styles except whole (count/kg)
08 to 12	up to 15	⩽21
13 to 15	16 to 20	22 to 33
16 to 25	21 to 25	34 to 44
26 to 30	26 to 30	45 to 55
31 to 35	31 to 35	56 to 66
36 to 40	36 to 40	67 to 77
41 to 50	41 to 50	78 to 88
51 to 60	51 to 60	89 to 110
61 to 70	61 to 70	111 to 132
71 to 90	71 to 90	133 to 154
	91 to 110	155 to 176
	111 to 130	177 to 198
	131 to 200	199 to 220
	201 to 300	221 to 286
	301 to 500	287 to 440
		441 to 660
		661 to 1 100
		⩾1 101

a/ Codex Alimentarius Commission, CAC/RS92-1976, Recommended International Standard for Quick-Frozen Shrimps and Prawns

Table 2

Size grading of frozen cephalopods

Whole squid (count/kg)	Squid fillets (count/kg)	Whole octopus (count/kg)
Up to 16		
16 to 20	up to 10	0.5 to 1.0
21 to 25	10 to 20	1.0 to 1.5
26 to 30	20 to 40	1.5 to 2.0
	40 to 60	2.0 to 2.5
	60 to 80	2.5 to 3.0
	80 and over	3.0 to 4.0

If, for some reason, there are two or more distinguishable quality grades of a given product, they should be marketed separately, preferably under a different brand name, so that the sale of the high quality grade does not suffer from its association with the lesser quality grade. For instance, delays before handling and freezing fish at sea can result in a quality grade which is less than the ideal achieved when the fish are frozen quickly after catching. In some countries it is the custom to label these fish so that they can be identified by the processor at the point of first sale and marketed either as a product where a lower quality is less critical or as a cheaper brand of the same product.

From the point of view of calculating the capacity requirement of the associated refrigeration plant, differences in the composition of fish seldom have any practical significance.

The refrigeration requirement depends to a great extent on the water content of the fish, therefore, fish with a high oil, shell or bone content and consequently lower water content would, in theory, require a lower capacity refrigeration plant than that required for such products as lean fish fillets. Individual calculations can therefore result in significant differences between the refrigeration requirement for one product and another. For example, the heat to be removed in reducing cod fillets from 10°C to -20°C is 76 kcal/kg, whereas the requirement for oysters in their shell is 36 kcal/kg. This considerable difference is due to the high shell content of the oysters, but the differences between different species of white fish, for instance, would be very little and of no practical significance.

The question to be asked at this stage, however, is whether the freezer is likely to be required to freeze a variety ofproducts either at present or in the future. If this is the case, then the freezer capacity should be based on the requirement for freezing fillets of lean fish, such as cod, since this requirement is likely to be the most demanding. The need for versatility is more likely to prevail when the requirement is for an air blast freezer since this type of freezer can be adapted to freeze products of a variety of shapes and sizes.

Other differences in chemical composition have little or no effect on the freezing requirement other than to depress the temperature at which freezing commences. Higher salt contents may depress the freezing point or temperature of "thermal arrest" which will be between -0.5°C and -1.0°C for most products. This is more likely in processed fish, such as smoked products, where the salt content is increased by brining and concentrated by drying.

2.2 Fish Handling

Prefreezing treatment starts immediately after the fish is caught, whether the fish are frozen at sea or eventually on shore.

Freezing does not improve the fish quality, but good freezing and cold storage practice can maintain the fish at the quality pertaining at the time they were frozen. Good quality frozen products, therefore, can only be achieved with good prefreezing practice.

All fish should be chilled rapidly, immediately after catching. Stowage in ice is the most widely used method of chilling either in boxes, on shelves or in ponds in the fish-hold. When large quantities of fish are caught and are difficult to handle quickly with normal icing methods, chilled sea-water (csw) or refrigerated sea-water (rsw) systems are used.

Chilling practice for fish prior to freezing is identical to that recommended for fish that are chilled and sold unfrozen. Quick chilling is important even when the time between catching and freezing is short, particularly in tropical countries where only a few hours exposure at ambient

temperatures may be equivalent to many days of chilled storage. This is illustrated in Figure 1 which compares the rate of bacterial growth at different temperatures.

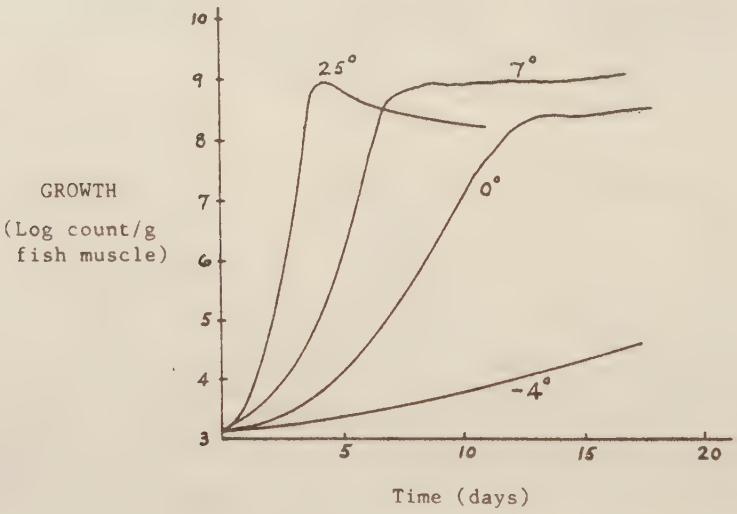


Figure 1 The effect of temperature on bacteria growth

Table 3 gives the maximum prefreezing storage times that should be allowed at 0°C after quick chilling to ensure a good quality frozen product. Little data exists, however, of corresponding times for higher temperatures, but reference to Figure 1 shows that they are likely to be extremely short and this situation should therefore be avoided.

Table 3

Prefreezing storage at 0°C
for a good quality product

Species	Prefreezing storage time (days)
Cod	3
Haddock	2
Lemon sole	5
Shark/dogfish	1
Herring	3/4 to 1
Sardines	1
Tuna	1
Shrimp (Pandulus)	up to 2
Salmon	up to 3

Prefreezing handling and storage is extremely important and the following documents should be consulted for detailed information:

- Codex document CAC/RCP-16-1978, Recommended International Code of Practice for Frozen Fish,
- Codex document CAC/RCP-9-1976, Recommended International Code of Practice for Fresh Fish,
- FAO document FIIM/T/167, Freezing in Fisheries,
- FAO document FIIM/R/59 (Rev. 1), Ice in Fisheries,
- FAO document FIIU/C735, Planning and Engineering Data, 1. Fresh Fish Handling

2.3 Preparation of Raw Material

Most operations in the processing of fish can now be done by cost effective machinery. The best conditions for machine processing pertain when labour costs are high and there is also a high degree of standardization in the product and processing requirement. Other factors, such as power availability and import restrictions on machines may, however, influence the choice between a manual or machine operation.

Most machine developments have been made initially to satisfy the conditions that pertain in temperate climates, although some machines have been specially developed, or modified, to meet a need for processing some species of tropical fish. Care, however, should be taken to ensure that a machine is suited to a specific requirement and that the yields and throughputs are measured values which apply to the species and quality of the fish to be processed. The following list gives information about machines used for the prefreeze processing of fish.

2.3.1 Gutting machines

Gutting machines are used on fishing vessels and on shore for marine fish, and also on fish farms for species such as trout. They open the belly and remove all parts of the entrails. The head is left on the fish. The liver, roe and milt are not collected.

Machines are designed for gutting cod, haddock, hake, trout, mackerels and similar fish of lengths from 25 cm to 75 cm, with a throughput of approximately 30 fish/min.

Floor area - 2.0 m^2

One operator

Power - 3 kW 220/380 V 3-phase

Water consumption - 35 litres/min

Cost - US$ 22 500

2.3.2 Scaling machine

Type of fish : flounders, bass, perch, pike, pollock, whiting, haddock, hake, herring and many other types of fish

Capacity of machine: 2 500 kg to 4 000 kg/h, depending on size and type of fish being scaled

Floor area required: 3.0 m^2

Operators : one

Power : 1.5 kW

Water consumption : 15 litres/min

Cost : US$ 7 500

2.3.3 Heading machine

Designed for heading: cod, haddock, pollock, and similar fish of lengths from 25 cm to 100 cm

Throughput : 35 fish/min

Floor area required: 3.0 m^2

Operators : one

Power : 1.5 kW 220/380 V 3-phase

Water consumption : 12 litres/min

Cost : US$ 10 000

2.3.4 Filleting machines

A manufacturer's range of machines is given in Table 4.

Table 4

Filleting machines

Type of fish	Fish size (cm)	Capacity (per min)	Yield (%)	Floor area (m^2)	Operators	Power (kW)	Water consumption (l/min)	Cost (US$)
Codling, haddock, pollock, whiting	25-42	40	47 with skin and belly flaps	4.0	one	2.5	13	36 000
Whiting and small haddock	25-40	40	47 with skin and dorsal fin	4.0	one	2.5	10	37 500
Cod, pollock, haddock and similar fish	30-70	24-40	50 skinless	12.0	one	10	30	105 000
Cod, pollock. haddock, hake and similar fish	30-55	25-40	45 skinless	4.0	one	1.5	15	37 500
Cod, haddock and pollock	35-70	24	47 with skin and belly flaps	3.5	one	2.5	25	39 000
Cod, pollock, haddock and hake	45-85	24-34	47 with skin and belly flaps	6.0	one	3	25	60 000
Herring	20-37	120-150	55	10.0	two	3	35	37 500

2.3.5 Skinning machines

Baader 51

This machine is capable of skinning fillets of any size cut from cod, pollock, merluza, haddock and redfish.

Operators : one or two

Throughput : 30-140 fillets/min

Power : 1.5 kW

Water consumption: 12 litres/min

Area : 2.0 m^2

Cost : US$ 15 000

Trio skinning machine (refrigerated drum)

Machine capable of skinning fillets of any size cut from herring, mackerel and white fish. The only machine suitable for skinning block fillets. The fillets are placed with skin - side up - on a special designed conveyor, which passes under a rotating refrigerated drum. By touching the drum the skin of the fish is immediately frozen to the drum surface and subsequently the skin and the flesh are separated by means of a band knife.

Operators : one or two

Throughput : herring and mackerel - 100-150 fillets/min
white fish - 30-60 fillets/min depending on size
maximum width of fillets - 330 mm

Power : 6.0 kW

Water consumption: 18 litres/min

Area : 3.5 m^2

Cost : US$ 27 000

2.3.6 Bone separator or mincing machines

This machine minces fish or separates the raw meat from bones, fins and skin. The fish pieces are fed into the machine through a filling hopper, then a conveyor belt of strong elastic material conveys the fish to a perforated drum. The meat is extruded through the perforations in the drum into the interior chamber while bones and other solid particles remain on the external drum shell, from which they are removed by a stripper.

When processing pin-bone V-cuts without skin, it is possible to obtain an edible fish yield of 90 percent.

Operators : one

Throughput: 400 kg raw material/h

Power : 1.5 kW

Area : 1.5 m^2

Cost : US$ 15 000

2.3.7 Battering and breading machines

Suitable for continuously battering and breading fish fillets, fish sticks, fish portions, etc.

The products to be breaded are put on a stainless steel conveyor belt of the batter machine either by hand or automatically. They then pass through a curtain of batter before moving to the breading machine where a layer of bread-crumbs, adjustable in thickness, is placed on the product. An air blower removes superfluous bread-crumbs.

Operators : one or two

Throughput: approximately 350 kg/h, depending on size of machine

Power : 2.5 kW

Floor area: approximately 4.0 m^2

Cost : US$ 22 500

2.3.8 Forming machine

Machines suitable for forming (moulding) a large variety of fish and other food products. Almost any combination of ingredients can be used which makes these machines highly flexible.

The shape of product can be formed by simply changing the forming set. The product is loaded into a self-feeding hopper; then it is forced into the forming plates by means of a piston. When they have been filled, the plates are moved forward to the knock-out position and the contents are deposited onto the outfeed conveyor.

Operators : automatic

Throughput: 2 000 kg/h (approximately)

Power : 7 kW

Area : 3.0 m^2

Cost : US$ 22 500

2.3.9 Automatic shrimp-peeling machine (comprising five machines)

(i) Peeler, (ii) cleaner, (iii) waste separator, (iv) deveiner, (v) grader.

These machines deliver completely peeled, deveined and graded raw shrimp meats for packaging or processing. The flow of shrimp is continuous and is accomplished by means of flumes or conveyors.

(i) Peeler

Peels approximately 400 kg of shell-on raw shrimp/h. Shrimp are bulk-loaded into an attached feeder-tank and are then carried by conveyor-belt into the machine where peeling is done automatically by a series of rollers which leave the shrimp meat on top.

Capacity : 300 kg/h

Power : 4 kW

Water : 300 litres/min

Floor area: 10 m^2

Cost : US$ 45 000

(ii) Cleaner

Detaches gristle and other waste appendages in a continuous gravity flow.

Capacity : handles output of two peelers

Power : 0.6 kW

Water : water with peeled meats from discharge of peeler is sufficient

Floor area: 3.0 m^2

Cost : US$ 4 700

(iii) Separator

This machine separates the waste material detached from the edible shrimp meats as a continuous process.

Capacity : handles output of two peelers

Power : 0.6 kW

Water : 50 litres/min

Floor area: 2.5 m^2

Cost : US$ 5 400

(iv) Deveiner

The deveiner takes fully peeled shrimp which are flumed with water into the machine directly from the peeling, cleaning and separating operation.

Shrimp slide down the sloping blades which slit the backs of the shrimp to expose the veins.

Fingernail-like projections on the drum wall separate veins from shrimp.

Capacity : handles output of two peeling machines

Power : 0.5 kW

Water : 200 litres/min

Floor area: 12.0 m^2

Cost : US$ 18 000

(v) Grader

Accurately grades all sizes of shrimp, using spiral rods which can be easily adjusted to successfully pass shrimp of different sizes.

Capacity : handles output of two peeling machines

Power : 0.5 kW

Water : 20 litres/min

Floor area: 1.5 m^2

Cost : US$ 3 200

Total floor area required for all five machines, when assembled in their correct positions, 80 m^2.

2.3.10 Weighing and grading machines

Machines specially developed for use in wet environments and suitable for weighing and grading wet or frozen fish.

Machines can grade up to 31 different weight classifications, all with user definable weight intervals, with speeds up to 200 weighing operations/min and can provide totalized and analysed production data on request.

Although machines can be purpose-designed or modified for individual products, existing models are mainly for the more common requirements ranging from small fillets to large cod.

A conveyor belt carries the product over the weighing machine where it is weighed with extreme precision. The product is then transferred to the conveyor belt on the grading unit where it is delivered into the appropriate bin by a pneumatic-controlled sorting arm.

Cost : machine with weight-range 0-2 500 g, US$ 33 000

Floor area: 15 m^2

2.4 Ingredients (Additives)

2.4.1 General

Most countries permit only very limited addition of non-nutrient ingredients (usually called additives) to unprocessed foods, and fish is no exception. The additives listed below include (i) additives that have been accepted by the Codex Alimentarius Commission for use in fish and included in Codex Standards, (ii) additives proposed in Draft Codex Standards, and (iii) additives known to be permitted in a number of countries. All the named additives have been approved for food use by the FAO/WHO Joint Expert Committee on Food Additives.

Food regulations of individual countries vary widely, and acceptance of Codex Standards by governments is, so far, limited. It cannot, therefore, be assumed that any of the additives listed will be widely permitted, and it is imperative that the regulatory authorities of the country of destination of the frozen product be consulted on:

(i) whether a particular additive is permitted in that product,

(ii) whether the amount that may be added is restricted, and

(iii) any specific labelling requirements.

The lists below include additives to fish fillets, to minced fish, to mixtures of fillets and mince, and to the fish component of composite products such as fish sticks. Additives appropriate only to non-fish components of such composite products are excluded. Also excluded are ingredients not normally subject to legislative control, such as salt, sugars, vinegar, herbs and spices.

Specifications of purity for many of the additives mentioned have been prepared by the Joint Expert Committee on Food Additives, but are not widely used. All additives should be of "food grade" quality and should meet any additional requirements of the country concerned.

It is difficult to estimate the cost of treatment with any of the additives listed, since the conditions of use vary so widely. As a broad generalization, the cost of materials for any of the treatments listed is unlikely to exceed 10 cents (US)/kg fish; this estimate does not include cost of labour and equipment employed.

2.4.2 Additives

2.4.2.1 Drip reduction agents: Soluble salts of phosphoric acids are the only commonly approved agents for minimizing drip loss on thawing. These additives also act as lubricants and binding

agents in the preparation of blocks of fillets, of minced fish, or of mixtures of fillets and mince. Many processors now use proprietary mixtures of phosphates, prepared for particular purposes, rather than the individual substances listed below.

Table 5

Phosphates

Tetrasodium or tetrapotassium diphosphate (also called sodium or potassium pyrophosphate)
Pentasodium or pentapotassium triphosphate (also called sodium or potassium tripolyphosphate)
Other linear sodium or potassium polyphosphates

These phosphates are added to fish most commonly as a 5-10% solution, either by dipping the fish in a large volume of the solution or by adding a small measured amount of solution to the fish and mixing.

Codex Standards and some national standards set limits on the amounts of added phosphate; in Codex Standards the maximum permitted amount is 5 g/kg of fish, calculated as phosphorus pentoxide (P_2O_5).

2.4.2.2 Binding agents: Phosphates, described in the previous section, act as binding agents by forming a sticky layer of swollen protein on the surface of a fillet. Many other substances, including natural and synthetic gums, have been proposed as binders. The most used are salts of alginic acid, especially the sodium, potassium and propylene glycol salts. As in the case of phosphates, they are usually applied as solutions in water. Codex Standards place a limit of 5 g/kg on the amount of alginates permitted.

A closely related use of alginates is as a component of glaze on frozen fish to improve the adhesion and flexibility of the glaze layer.

2.4.2.3 Preservatives: The use of preservatives in unprocessed fish is very limited. Codex Standards and some national regulations permit the use of sulphur dioxide in raw crustacean shellfish to minimize certain specific deteriorative reactions such as development of "black-spot" on shrimps and prawns. The permitted limits laid down in Codex Standards are 100 mg/kg in the raw product and 30 mg/kg in the cooked product, calculated as sulphur dioxide. Sulphur dioxide is a gas and is usually applied in the form of a solution of a salt of sulphurous acid; sodium metabisulphite ($Na_2S_2O_5$) is the most commonly used salt.

2.4.2.4 Antioxidants: The only antioxidant widely permitted in fish is ascorbic acid (Vitamin C), used either as the acid or its sodium or potassium salt. The maximum amount permitted in Codex Standards is 1 g/kg, calculated as ascorbic acid. It is usually added as a solution.

2.4.2.5 Dyes: The use of dyes on unprocessed fish is not widely permitted. In Codex Standards, a very limited range of dyes is allowed on frozen cooked shrimps and prawns, but on no other frozen fish. Frozen processed fish may contain dyes; smoked fish, for example, is often dyed to give a more pleasing and uniform colour. The dyes permitted for such purposes vary so widely from country to country that it is not possible to give any useful list of dyes. Not all dyes have been approved by the Joint Expert Committee on Food Additives mentioned earlier.

2.5 Products

2.5.1 General

Although fish are frozen in a variety of ways to give a wide range of fish products, most of them can be included in the following main categories:

- Invididually quick frozen (IQF) - single fillets, whole fish, fish portions or products frozen so that after freezing they remain separate. This method of freezing allows quantities to be removed from storage at intervals to meet the exact requirements of the consumer.

- Fish blocks - fish or fish products frozen in large, compact blocks in vertical plate freezers. This gives regular shaped blocks which store at a high density and it is the form in which fish are usually frozen in bulk for processing later.

- Laminated blocks - regular shaped, homogeneous blocks of frozen fish fillets or mince frozen in a horizontal plate freezer. This form of frozen product is used in the preparation of frozen fish fingers and portions.

- Packaged frozen fish - a variety of fish products frozen in all types of freezer to give both retail and commercial packs. Large quantities of regular shaped packs would normally be frozen in a horizontal plate freezer.

2.5.2 Small pelagic

Small pelagic fish may be frozen on board in either:

(i) vertical plate freezers, preferably in polythene or coated paper bags inserted between the plates with or without water added;

(ii) horizontal plate freezers in cartons;

(iii) air-blast freezers in cartons.

Vertical plate freezers are the most widely used when the fish are to be frozen in bulk for later processing on shore, and Table 6 gives information on some of the more typical blocks produced in this way.

Table 6

Whole pelagic fish frozen in vertical plate freezers

Weight (kg)	Dimensions (mm)	Density t/m^3	No. of blocks/ pallet (t)	Stowage rate incl. pallet m^3/t
22.5	1 060 x 520 x 50	.8	44	1.6
22.5	530 x 520 x 100	.8	44	1.6
45	1 060 x 520 x 100	.8	22	1.6

If small pelagic fish, such as herring, are frozen in the form of fillets, it is more acceptable to freeze them as smaller blocks in a horizontal plate freezer. Blocks of 3.5 and 7 kg frozen in cartons with polythene interleaving between the layers of fillets are typical products.

Whole fish, packed as shown in Figure 2, may be frozen in an air-blast freezer to give blocks of 3.5-7.5 kg.

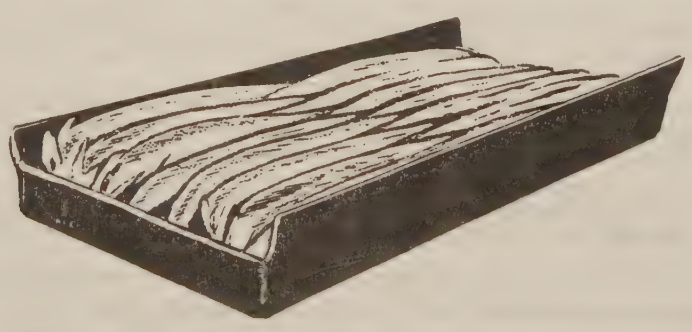


Figure 2 Tray for air-blast freezing small, whole fish

2.5.3 Whole demersal

Air-blast frozen fish can be individually quick-frozen by laying them out on trays which are then loaded into the freezer on trolleys or pallets. Some larger fish, or fish such as salmon which are often required to be frozen so that they retain their rounded shape in the frozen state, can be frozen by hanging them from suitable racking in the freezer or on a trolley. Whole fish may also be frozen in trays with the fish packed head-to-tail, as shown in Figure 2.

Fish, such as halibut and shark, may be too large to freeze whole in the main freezer and, if space and requirement justifies the need, a small freezer room may be constructed where they can be frozen slowly in the vertical hanging position. This freezer room can also be used as an additional cold store for frozen product.

Freezing by immersion or spraying with sodium chloride brine has also been used in the past for whole fish, but fish frozen by this method would have a restricted market due to salt uptake, and the method is now little used.

2.5.4 Tuna

Depending on the species and form of the end product, tuna are frozen using one of the following methods:

(i) by immersion in sodium chloride brine,

(ii) by spraying with sodium chloride brine,

(iii) by blast-freezing - in a batch or continuous freezer,

(iv) by "sharp" or semi-air-blast freezing,

(v) by plate freezer,

(vi) by immersion in calcium chloride brine.

Freezing with sodium chloride brine is used where the end product is to be canned and mainly on smaller fishing vessels only. Disadvantages with this type of freezing are that the temperature of the fish cannot be reduced much below -15°C, and care has to be taken to limit the salt uptake. After the fish has reached this temperature, the brine is drained off and the tuna may be further reduced in temperature during a period of "dry" cold storage. The fish require to be at least partially thawed to facilitate discharge at the cannery. More than 50% of almost 2 million tons of world catches of "true" tuna (i.e., yellowfin, bluefin, albacore, bigeye and skipjack) end up in a can.

Most on-board freezing is done by a so-called semi-air-blast method in an insulated room which has a capacity to hold about 2 t of fish. In the freezer, very cold air at a temperature from -55° to 60°C is circulated by two fans of about 1.5-2.0 kW and it usually takes up to 36 h to freeze the fish to -45°C at the deepest part of the fish. Larger fish, however, may take up to 72 h. After freezing, the fish are glazed before storage in an insulated hold.

Some of the larger tuna clippers are equipped with calcium chloride brine immersion freezers which have an advantage over the air-blast freezers in terms of reduced freezing times and lower energy consumption. Brine may be considered a problem due to residual calcium chloride, but since this only penetrates to a few millimetres below the surface, particularly if they are frozen pre-rigor, there is a wide acceptability by consumers.

Some operators pre-wrap the fish before immersion in calcium chloride brine and with this method it is possible to store the fish immersed in the brine until they are discharged.

Cold stores used with air-blast and calcium chloride brine freezers usually have floor, wall and roof cooling grids. This type of cold store cooling tends to be more expensive, but the method is used to ensure that product dehydration during storage is kept to a minimum.

Correct stacking of large tuna fish in a cold store is important in order to achieve load stability and also the maximum use of the storage space.

Tuna fish between 20 and 150 kg are usually frozen whole after they have been bled and washed, after the gills are removed (semi-dressed).

Fish of more than 150 kg are semi-dressed, then cut into two fillets. The fillets are then cut further into ½- or 1-kg portions which are then vacuum packed in polyethylene bags, sealed and frozen.

Flesh colour is a major quality consideration for fish used in the preparation of sushimi and sushi and the rate of change of the colour from red to an unacceptable brown during storage depends on the storage temperature. Storage temperatures of -40°C and below are therefore recommended, and since there is a tendency for prices to be higher for fish stored at lower temperatures, processors are encouraged to operate their stores at -50°C or even -60°C.

It has been demonstrated that temperature is closely related to quality of the tuna and for this reason there has been a continual lowering of freezing and storage temperatures on board the

vessels catching fish other than for canning. Temperatures of between -50°C and -60°C are now common for freezing rooms and fish-holds.

2.5.5 Frozen blocks (demersal)

Freezing in vertical plate freezers is the method mainly used for producing blocks of whole fish. Blocks of fillets can also be prepared, usually in the smaller blocks thicknesses only and by using partitions in the freezer to produce smallest blocks. Blocks can vary in thickness and other dimensions, depending on the size of fish to be frozen with, in general, thinner blocks being made with smaller fish and fillets. Optimum block dimensions will depend on the size range of the fish being frozen, but there may not be a requirement to freeze all sizes. For example, block dimensions of 1 060 x 520 x 50 mm were used for frozen-at-sea North Atlantic cod and this was suitable for about 98 percent of the catch; large fish were either headed to allow them to fit into the freezer or individually frozen in a freezer room.

A typical standard range of block dimensions and weights now available for freezing whole fish and fillets is given in Table 7.

Table 7

Vertical plate frozen blocks of demersal fish

Product	Block thickness (mm)	Block dimensions (mm)	Block weight (kg)
Whole haddock	50	1 060 x 520	25 nominal
Whole haddock	75	1 060 x 520	37 "
Whole cod	100	1 060 x 520	50 "
Cod/haddock fillets	50	1 060 x 520	27.5 "
Cod/haddock fillets	50	530 x 520	13.7 "
Cod/haddock fillets	65	1 060 x 520	36 "
Cod/haddock fillets	65	530 x 520	18 "

Blocks of fish can also be frozen in air-blast freezers with the fish packed in metal containers and stacked on trolleys or pallets. The containers require to have well tapered sides in order to release the fish after freezing, usually by spraying water on the underside. Blocks frozen in this way are normally packed in cartons before storage and one reason for this is that they are not regular shaped, flat-sided blocks and, therefore, difficult to stack.

Frozen blocks can also be made by packing the smaller demersal fish in cartons and freezing in a horizontal plate freezer, and when freezer frames are used, block dimensions can be standardized.

2.5.6 Shrimp/prawn

2.5.6.1 Whole shrimp: Whole shrimp can be frozen at sea by immersion freezing in a sodium chloride brine or sugar and salt solution, by plate freezing or by freezing in an air-blast freezer.

Freezing in sugar and salt solutions is claimed to give an improved glaze on the shrimp, makes them more attractive and also ensures that the shrimp remains separate to give an individually quick frozen product. This method of freezing, however, will result in flavour changes which may not always be acceptable.

Shrimp frozen in a vertical plate freezer are poured into polyethelene bags inserted between the plates, and water is added to strengthen the block, improve heat transfer and protect the product during subsequent cold storage. The frozen blocks are usually packed in master cartons, made from plain or corrugated fibreboard, for storage.

Cooked whole shrimp can be satisfactorily frozen in a vertical plate freezer, but freezing by immersion is not normally recommended since this makes the shrimp difficult to peel and the meat texture is also adversely affected.

The above methods of freezing are equally applicable to freezing on shore, but in order to give a good quality product the shrimp should not be stored for more than two-three days at chill temperatures from the time of capture.

Another method of freezing, widely used in factory operations, is to freeze whole shrimp or unpeeled tails into 2-kg blocks in horizontal plate freezers. The shrimp are loaded into metal moulds and water added to fill the voids. After fixing on the lid the moulds are loaded into the freezer on metal trays and frozen to give solid blocks of shrimp with a net weight of about 2 kg. After freezing, the blocks are released from the moulds by spraying the underside with potable water and they are then packed into plastic bags or cartons. The packages are packed into master cartons for cold storage.

2.5.6.2 Meats only: Peeled meats are frozen raw or cooked as individually quick-frozen products or in blocks or packages.

Small shrimp should always be individually frozen in a continuous freezer, either air-blast or cryogenic, since even short delays, which may be inevitable with a batch freezer, will result in a product temperature rise and even partial thawing.

Continuous belt freezers may be used for both cooked and uncooked produce but, for cooked meats only, a freezer, known as a fluidized bed continuous freezer, is also satisfactory. With this freezer there will, however, be an additional weight loss due to the agitation of the product in the freezer, but the pulped meat or formed mush can be collected and utilized in some way.

A semi-fluidized bed freezer can also be used for cooked meats with a reduced agitation weight loss. In this freezer, agitation is only applied at the start of freezing to achieve a separation of the shrimp and a belt is then used to convey the product through the rest of the freezer.

Meats are also frozen in small blocks in horizontal plate freezers for markets which may require them to be thawed and reprocessed before sale. Packaging in metal moulds, but within plastic bags or with a completely overlapped plastic liner, is one method which requires packaging after freezing. Inner plastic bags and outer cartons is another, which gives a finished product. Retail and catering packs can also be made in a similar fashion.

2.5.7 Fillets

The two main frozen fillet products are individually quick-frozen fillets (IQF) and fillet blocks.

IQF fillets may be frozen skin-on or skin-off and various prefreezing and post-freezing treatments, such as polyphosphating and enrobing in batter and bread-crumbs, may influence the choice of freezer.

Ideally, IQF fillets are better to be frozen in a continuous freezer, and air-blast, cryogenic and drum freezers have been used for this purpose.

Batch freezing of fillets is also viable in an air-blast freezer with the fillets laid out carefully on trays placed on shelves, trolleys or pallets. This method, however, is labour intensive and unless the fish are packaged and stored quickly after freezing, some thawing, particularly of thinner fillets, may result.

Fillets are also frozen as blocks in horizontal plate freezers with interleaving of a plastic film so that individual fillets may be removed by the consumer without thawing.

Skinless fillets are frozen into regular shaped, homogeneous blocks in horizontal plate freezers and this product is then cut up to form fish portions or fish fingers.

Fillet blocks are also frozen in horizontal and vertical plate and air-blast freezers for bulk storage and later processing. However, the advantage gained by freezing the fish flesh only, rather than whole fish, may be lost due to the greater susceptibility of fillets to adverse quality changes during subsequent cold storage.

Tables 8 and 9 list a number of frozen fillet products for retail and catering sales.

2.5.8 Minced and/or formed frozen fish products

This category covers a wide range of products with fish fingers and fish portions being the most widely recognized and accepted products.

Fish fingers and fish portions are made from regular shaped blocks of fish which may be made wholly from fish fillets or fish mince or a combination of the two raw materials. The blocks are sawn or cut, after tempering, into the size and shape required and often this type of product is enrobed with a batter and bread-crumb coating. The coating process is usually followed by "flash frying" in a cooking fat, which partially cooks the product and also helps to bind the coating. The

Table 8

Individually quick-frozen fillets - polystyrene trays with stretch wrap

Product	Wt of pack (kg)	No. in pack	Type of pack	Dimensions of pack (mm)
IQF Fillets	.284	-	Poly tray with wrap	188 x 135 x 30
"	.227÷.298	-	"	220 x 130 x 30
"	.255÷.369	-	"	270 x 138 x 18
"	.173÷.355	-	"	215 x 130 x 30
"	.184÷.340	-	"	264 x 131 x 25

Note: The fillets in the pack might be above the level of the top of the tray; this must be allowed for when calculating density or stowage rate

Table 9

Individually quick-frozen fillets - polyethylene bags and cartons

Product	Wt of pack (kg)	No. in pack	Type of pack	Dimensions of pack (mm)
IQF Fillets	.700	-	Poly Bag	
"	.800	-	Poly Bag	
"	.907	-	Poly Bag	356 x 258
IQF Fillets	2.7	-	Carton	374 x 235 x 100
"	3.2	24	Carton	379 x 238 x 115
"	3.6	24	Carton	379 x 238 x 115
"	4.1	-	Carton	333 x 250 x 150
"	4.5	-	Carton	375 x 284 x 100
"	6.4	-	Carton	410 x 270 x 185
"	9.1	-	Carton	435 x 278 x 250

heat added during this forming process must be removed before the frozen product is placed in cold storage; therefore, further freezing, in or outwith the final retail pack, is necessary. Continuous freezers, either air-blast or cryogenic, may be used to cool and refreeze the individual portions or, if these are packaged in regular shaped cartons or other containers, this final freeze may be done in a horizontal plate freezer.

A variety of machines is now available for forming fish products from fish mince, cuttings and fillets. In addition, countries have their own specialist fish products, such as fish cakes in the UK, fish balls in the Scandinavian countries and surimi in Japan. All of these products may require special freezing facilities, such as arrangements to feed the freezers directly from the forming

machines. This type of product is more likely to be processed with an inline production system, therefore, continuous air-blast or cryogenic belt freezers are the type likely to be used. The freezer conveyor belt may also require to be made from a flat sheet material rather than the link or mesh type of belt normally used, since the flat belt ensures a quick release without damage to the product.

Tables 10 and 11 list some of the frozen fish products made in the UK, and they show the different methods of packaging and range of packs sizes usually produced for products of this kind.

Table 10

Fish fingers in cartons and bags

Product	Wt of pack (kg)	No. in pack	Type of pack	Dimensions of pack (mm)
Fish Fingers	.150	6	Carton	110 x 110 x 30
"	.255	10	Carton	182 x 100 x 32
"	.580	24	Carton	200 x 100 x 55
"	2.890	120	Carton	280 x 196 x 112
Fish Fingers	.850	36	Bag Pack	115 x 95 x 135
"	1.450	60	Bag Pack	170 x 100 x 155

Table 11

Fish portions battered and flash-fried

Product	Wt of pack (kg)	No. in pack	Type of pack	Dimensions of pack (mm)
Cut cod Portions	.2	2	Carton	174 x 118 x 28
"	.6	6	Carton	172 x 116 x 61
Machine formed Cod Portions	.2	2	Carton	182 x 117 x 28
"	.6	6	Carton	185 x 114 x 72

3. PROCESSES AND EQUIPMENT

3.1 Sources of cold

3.1.1 General

3.1.1.1 Basic refrigeration systems: Refrigeration is a process whereby heat is removed and rejected, and this can be achieved by any of the following methods:

Vapour compression
Vapour absorption
Air cycle
Thermoelectric

The most widely used is the vapour compressions system and only in exceptional circumstances would another method be contemplated in a modern fish processing installation. Even applications which apparently do not use this method, such as chilling with ice or freezing with a cryogenic liquid, are indirect uses of the vapour compression system, since such a system would have been used to make the ice or liquify the gas.

Vapour absorption is still used in some domestic refrigerators and there has been a revival of interest in this system for some commercial applications since it can be operated from a waste heat source. The absorption system does not require mechanical power, therefore, there is no requirement for an electrical supply of direct drive engine. The only requirement is an input of heat, therefore, this type of refrigeration system may be considered for limited applications in situations where a heat source is cheaper or more readily available than an electrical or mechanical drive.

The air cycle system is inherently safe and is now almost exclusively used for cabin cooling in aircraft.

The thermoelectric cooling system is confined to use with applications which require very small refrigeration effects, such as instrument cooling and laboratory use.

Other methods have been used, but they either have not been suitable for commercial operations or have now become obsolete for a variety of other reasons.

Cryogenic refrigeration, as mentioned above, is an indirect application of the vapour compression system and liquid nitrogen and liquified or solid carbon dioxide cryogenic systems have a limited application in fish processing.

A high purity fluorocarbon refrigerant, R12, is also used in immersion or spray cooling systems, but again there is only a limited use in the fishing industry.

3.1.1.2 Refrigerants: Although there are a wide range of refrigerants available, many have properties which suit them for special purpose applications only. The refrigerants listed in Table 12 are those commonly used in the fish industry and a number of secondary refrigerants, such as ethyl alcohol, methyl alcohol, glycol solutions and salt/sugar solutions, have also a limited use.

The choice of refrigerant is usually based on technical requirements, but other considerations, such as safety, high costs or import controls, may result in a compromise choice being made.

Table 12

Refrigerants

Designation	Chemical name	Trade names
Primary R12	Dichlorodifluoromethane	Freon 12, Arcton 12, Iceon 12
R22	Chlorodifluoromethane	Freon 22, Arcton 22, Iceon 22
R502	Azeotrope of R22 and R115 (Chloropentafluoroethane)	Freon 502, Arcton 502, Iceon 502
R717	Anhydrous ammonia	
Secondary	Calcium chloride brine	
	Sodium chloride brine	
	Trichloroethylene	Triklone A

The cost of refrigerants depends on the unit quantity (size of cylinder) and the quantity (weight) ordered. The costs listed in Table 13 are 1983 UK values for the quantities and unit containers specified. Initial costs may also include an additional deposit for the refrigerant containers.

Many of the physical properties of a refrigerant are important to the design engineer and this information is now readily available in suppliers catalogues and in text books. Only some of their attributes and likely applications are, therefore, given in the following notes.

(i) Refrigerant 12 has a relatively low latent heat value and this is an advantage in small machines since the higher flow rates required allow for better control. R12 is usable down to lower temperatures, but below -29.8°C negative pressures will prevail on the low pressure side of the system with potential problems resulting from leaks of air and

Table 13

Refrigerant costs

Refrigerant	Cost (US$)	Unit quantity
R12	1425/1000 kg	67 kg cylinder
R22	2550/1000 kg	60.5 kg cylinder
R502	3675/1000 kg	62.2 kg cylinder
R717	1095/1000 kg	69 kg cylinder
Calcium chloride	100/t	50 kg or bulk
Sodium chloride	8/50 kg	50 kg or bulk
Trichloroethylene	820/1000 kg	304 kg

moisture. R12 is completely miscible with oil at all likely operating temperatures, therefore, oil return systems are relatively uncomplicated.

(ii) Refrigerant 22: This refrigerant is mainly used as a replacement for R12 at lower evaporating temperatures since a positive pressure will prevail throughout the system down to a temperature of -40°C. It is, therefore, more likely to be used than R12 when there is a requirement to freeze and store fish at temperatures of -25°C or lower. R22 is completely miscible in oil down to a temperature of -9°C, but at lower temperatures there is a separation with oil collecting on the surface of the refrigerant. With the flooded systems used for most fish-freezing operations, special measures will therefore be necessary to return oil from the low-pressure receiver to the compressor.

(iii) Refrigerant 502: This azeotropic mixture of R22 and R115 combines some of the good properties of R12 and R22. For instance, it allows positive pressure operation at lower temperatures like R22, but it has also some of the oil miscibility qualities which are desirable and similar to those of R12. It is, however, more costly and this, together with availability, may be major factors relating to the use of this refrigerant.

(iv) Refrigerant 717 (ammonia): In spite of some of its unfavourable qualities, ammonia is still the most widely used refrigerant for larger installations. In terms of evaporator-operating temperatures, its properties are between those of R12 and R22, and since leaks into an R717 system do not have the long-term damaging effects as those experienced with halo-carbon refrigerant systems, R717 is suitable for nearly all fish-freezing and cold-storage operations. R717 has a highly irritant effect on the eyes and nose, therefore, small leaks can be readily detected and repaired without the need for systematic testing, as is the case with other refrigerants. In the presence of water it is corrosive to many non-ferrous metals, therefore, copper, which is widely used with other refrigerants, cannot be used in pipes, evaporators, instruments and controls. R717 forms an explosive mixture when mixed in the right proportions with air, therefore, special precautions should be taken to avoid the presence of nearby sources of ignition when major leaks occur. The use of R717 may be restricted; for instance, it is not used on fishing vessels in the UK. Oil separates out from R717 at low temperatures and, with the oil being the heavier, it has to be periodically removed from the bottom of the evaporators and low-pressure receivers.

(v) Calcium and sodium chloride brines: The main difference in the choice between these is that sodium chloride is cheaper and more readily available whereas calcium chloride brines can be used for lower temperatures. Although still used for some applications, such as tuna freezing, they are now seldom required for other fish-freezing and storage requirements since the development of primary refrigerant, pump circulation systems. The advantage of a secondary refrigerant is that it allows a finer control and more balanced circulation to multiple-unit installations. In larger installations where the refrigerant change in the evaporator or heat exchanger may be considerable, secondary refrigerant systems may be generally cheaper since they reduce the charge of the more expensive primary refrigerant. There is also no need to contain the bulk of the refrigerant in a system which has to withstand the higher standing pressure of a primary refrigerant; therefore, cooler construction will be cheaper and refrigerant losses less expensive.

The use of secondary refrigerant, however, means that the system is inherently less efficient since an additional temperature difference must exist between the primary and secondary refrigerants for heat exchange. The present unpopularity of calcium and sodium chloride brines is also partly due to their corrosive nature and the unpleasant and messy effects of spillage.

(vi) Trichloroethylene: This secondary refrigerant was widely used in UK freezer trawlers. It has far from the ideal qualities desirable in a secondary refrigerant, but its use avoided the distribution and leak problems associated with using a primary refrigerant in a multi-unit plate freezer installation on board a fishing vessel. It also allowed lower temperatures to be used than would be the case if a calcium chloride brine had been used. Trichloroethylene vapour is toxic and consideration should be given to potential health hazards before contemplating its use.

3.1.1.3 Power and consumption factors: The power required for a given refrigeration effect changes with operating conditions and this is illustrated graphically in Figure 3 where the power requirement for a nominal refrigeration effect of 20 000 kcal/h is given.

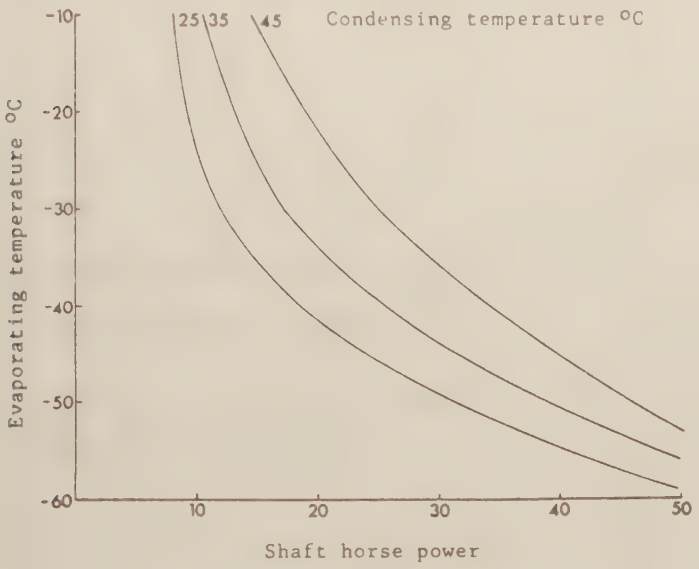


Figure 3 Compressor power requirement for a 20-kcal/h refrigeration plant

For any given compressor the capacity and power change significantly with changes in operating conditions, particularly those relating to the pressure/temperature of the refrigerant at the suction inlet to the compressor, and this is shown graphically in Figure 4.

The capacity of the compressor reduces at a greater rate than the power, therefore, the power per unit refrigeration effect increases and the corresponding values to the changes shown in Figure 4 are given in Figure 5.

In many situations it may be necessary for the factory to generate its own electricity, either because it is cheaper to do so or supplies from outside sources are unreliable. For this purpose a diesel generator would normally be used and the power output and electrical generation, characteristic for a range of units, is shown graphically in Figure 6. Fuel consumption for this range of diesel generators is shown in Figure 7 and, for budget purposes, ex-factory costs are given in Figure 8.

3.1.2 Mechanical refrigeration

3.1.2.1 Refrigeration systems: Mechanical refrigeration can be achieved in a variety of ways with various degrees of refinement used to achieve greater versatility, more accurate control, improved economy and other objectives.

The basic mechanical refrigeration system is shown in Figure 9 and, in simple terms, it is designed to take in heat at the evaporator and thereby reduce the temperature of the surroundings. The heat taken in is then raised to a suitable temperature by compression of the refrigerant gas and this allows the heat to be rejected to a fluid, such as water or air, at the condenser together with the heat of compression.

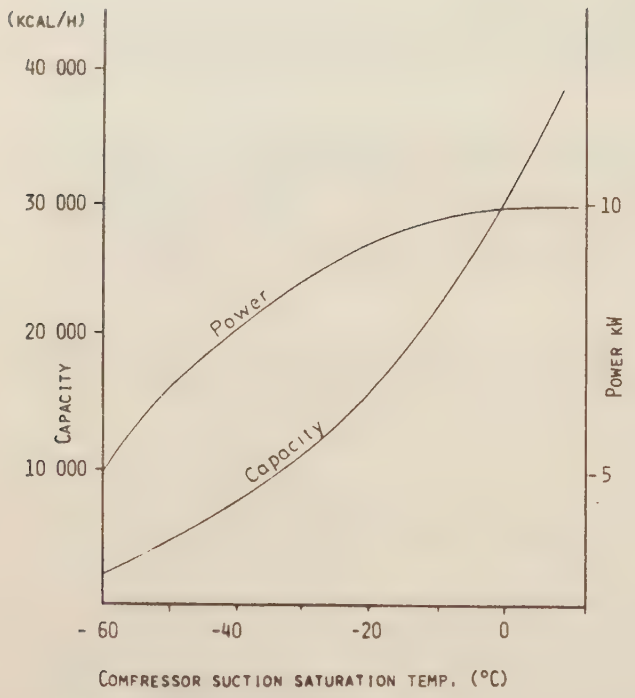


Figure 4 Variation in power and capacity of a compressor with changes in compressor suction conditions

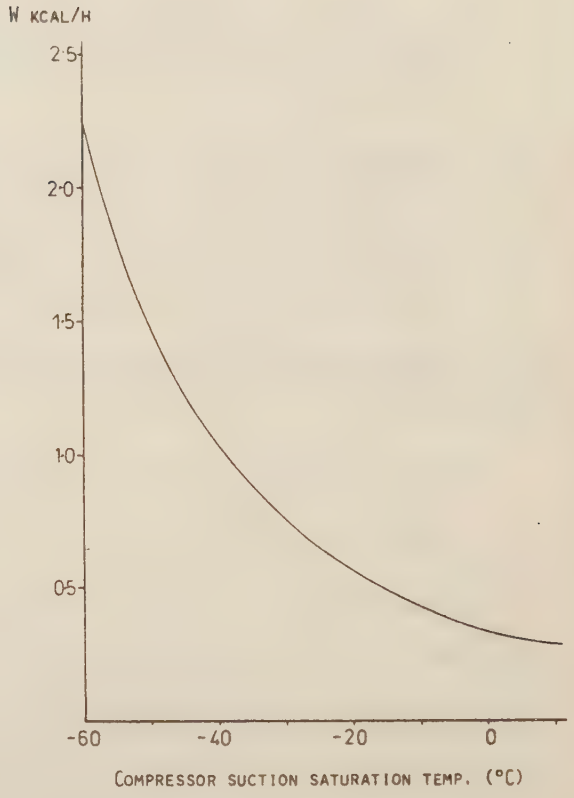


Figure 5 Power requirement per unit refrigeration effect with changes at compressor suction operating condition

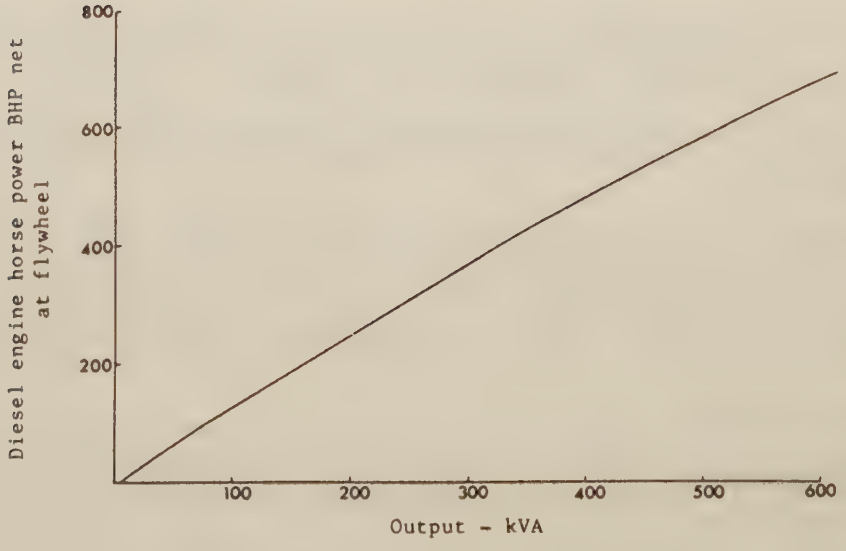


Figure 6 Horse power and output of diesel electric generators

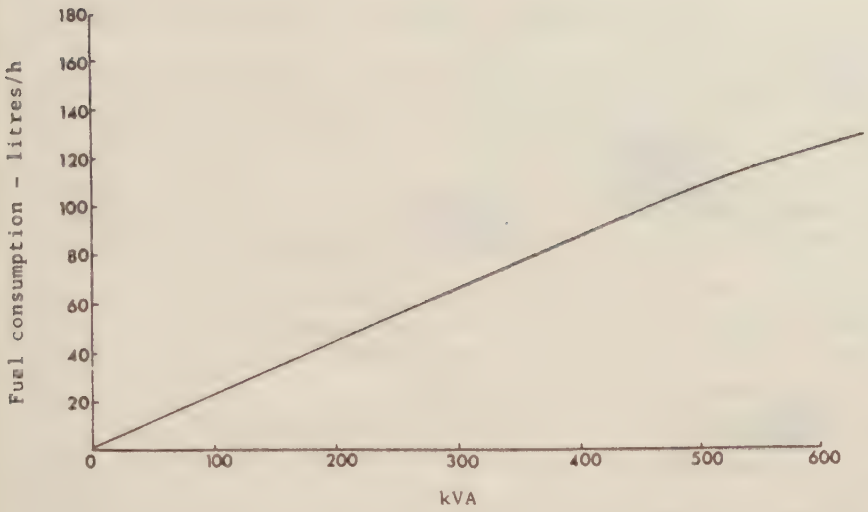


Figure 7 Fuel consumption of diesel electric generators

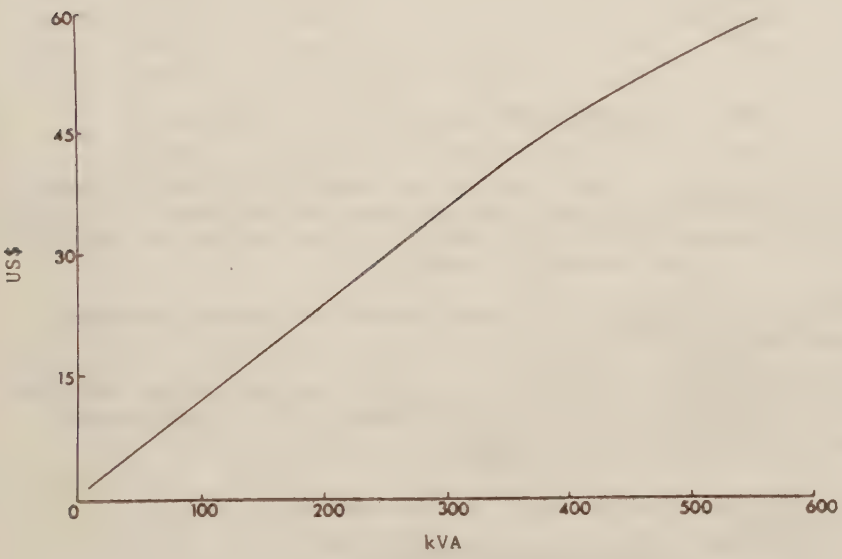


Figure 8 Cost of diesel electric generators

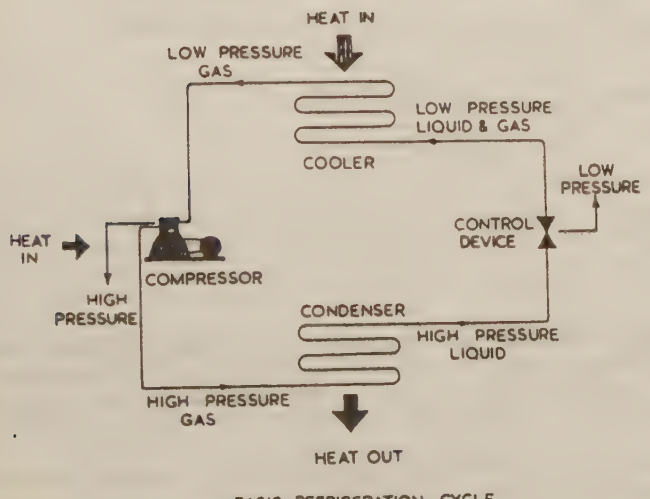


Figure 9 Basic mechanical refrigeration system

Refrigeration is therefore a continuous process with the refrigerant changing from liquid to gas, to liquid, as heat is added and lost.

Four basic systems using mechanical refrigeration are used for fish freezing and cold storage, and these are shown diagrammatically in Figures 10, 11, 12 and 13, with notes on the type of application where they are likely to be used.

(i) Dry expansion system: Used in all the small installations and in installations where there are not likely to be problems with refrigeration distribution or the temperature fluctuations induced by the cycling of the thermostatic expansion valve.

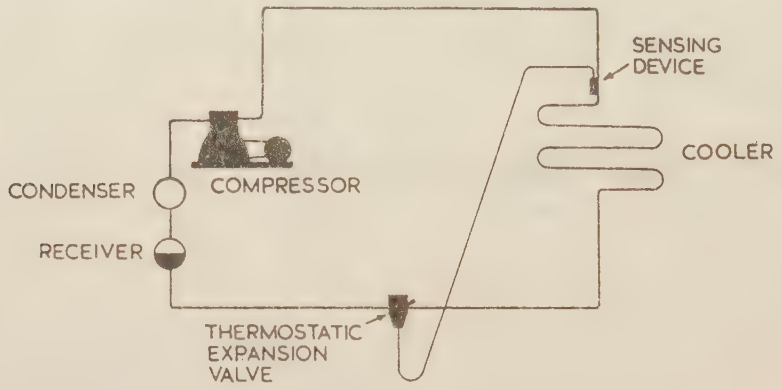


Figure 10 Dry expansion system

(ii) Flooded system with natural circulation: The flooded system gives a better heat transfer than the dry expansion system since there is more liquid present in the cooler. A flooded system also ensures better refrigerant distribution, therefore, they are appropriate when there are a number of parallel circuits for the refrigerant flow.

The reservoir in a natural circulation system is situated above the coolers, therefore, it is not suitable for widely separated multiple units.

The most appropriate application likely in fish freezing is with horizontal plate freezers which are single units with a number of parallel circuits formed by the freezer plates.

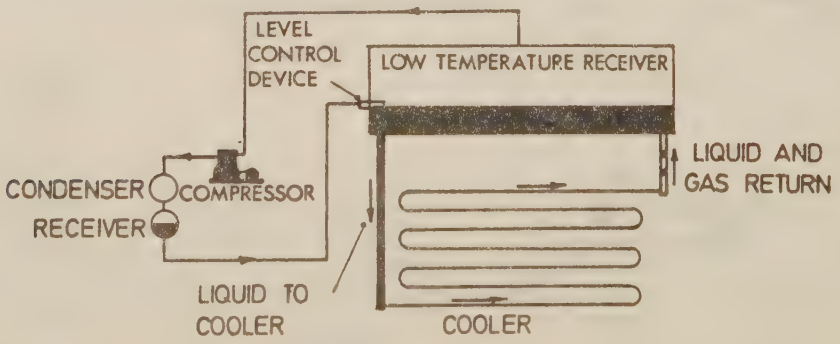


Figure 11 Diagram of natural convection flooded refrigeration system

(iii) Flooded system with pump circulation: Pump circulation allows a flooded system to be used with its advantage in good heat transfer and refrigerant distribution, in a multiple unit system with the low-temperature liquid reservoir situated, if necessary, away from the immediate vicinity of the coolers.

An example of this kind of application is a number of vertical plate freezer units supplied from a common liquid receiver sited in a separate engine room.

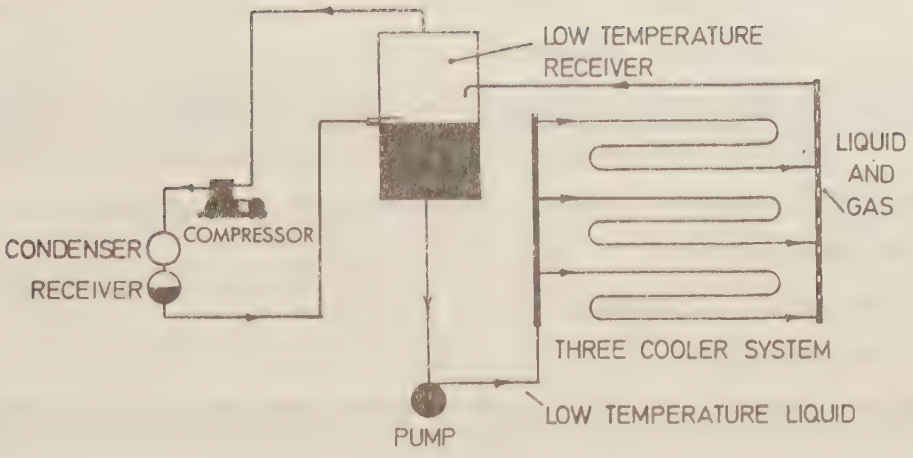


Figure 12 Flooded refrigeration system with pump circulation

(iv) Secondary refrigerant system: This has all the advantages of a pump-circulated flooded system without the need to have a pipework and cooler system suitable for the higher refrigerant pressures. The system would therefore be appropriate when there is a high potential for leaks such as on a fishing vessel. The primary refrigerant is confined to the condenser unit and heat exchanger only, and this may be located in a separate engine room.

A secondary system also avoids the potential problems that may result from having a large charge of a volatile refrigerant in a working space such as a factory floor or in a cold store (Figure 13).

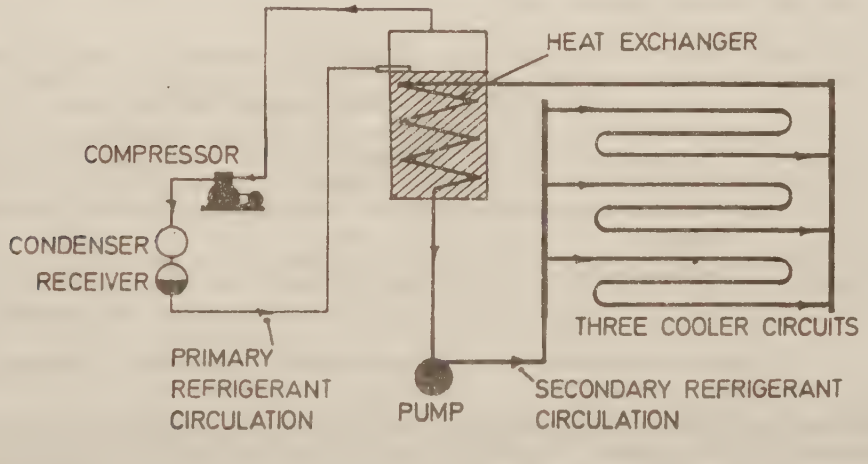


Figure 13 Diagram of secondary refrigeration system

3.1.2.2 Compressors: The function of a compressor is to draw refrigerant vapour from the evaporator and thereby create a low pressure so that the liquid refrigerant boils and achieves the desired heat exchange at a low temperature. The compressor also raises the pressure and thereby the temperature of the refrigerant vapour, so that it can transfer its heat to the cooling air or water at the condenser and, as a result, the refrigerant is liquified.

A compressor is in effect a pump which also creates the necessary conditions for heat transfer at the evaporator and condenser.

Compressors used in refrigeration may be divided into two main classes:

(i) positive displacement compressors, and

(ii) kinetic displacement compressors.

Only positive displacement compressors are likely to be considered for fish freezing and storage applications and, of this class, reciprocating compressors are by far the most widely used. Screw and rotary compressors, however, may also be used with advantage under certain circumstances.

Reciprocating compressors can be further divided into three categories:

(i) hermetic compressors,

(ii) semi-hermetic compressors, and

(iii) open compressors.

Hermetic compressors are part of a totally sealed system which also includes the drive motor, condenser and evaporator and they are widely used in small units since they require little maintenance.

Semi-hermetic compressors may be part of a sealed or open system and their main feature is that the drive motor and compressor are combined in a single unit so that there is no requirement for a drive shaft seal. The compressor and drive motor, however, can be separated for maintenance and repair. Their use is confined to relatively small installations requiring a compact compressor/motor unit.

Open type compressors are separate from their drive motor and are operated by means of a shaft with a rotary seal. Motor and compressor are completely accessible for maintenance and repair as separate units and the size range available covers most likely applications in fish freezing and cold storage.

Open type reciprocating compressors are made as units which may have up to 16 cylinders with six and eight cylinders being usual in commercial fish-freezing operations. Cylinder arrangements can be vertical and in-line or, in more modern compressors, arranged in W, V or WV formation to achieve a better balanced and a more compact unit.

Table 14

Size range of reciprocating compressors

Type	Minimum (hp)	Minimum (kW)	Maximum (hp)	Maximum (kW)
Hermetic	1/12	0.08	3/4	0.56
Semi-hermetic	1/4	0.18	80	60
Open	1/3	0.25	maximum requirement likely	

Multiple-cylinder units can be operated with a manual or automatic arrangement which involves off-loading some of the cylinders to give a stepped capacity control. This off-loading arrangement is often used during start-up procedures and larger units also use off-loading rather than frequent stopping and starting in order to achieve a controlled condition.

Compressors used for applications which give rise to high compression ratios (usually the result of low evaporator pressures) may require to be operated with a two-stage compression arrangement. This improves the economy of the compressor and also prevents excessively high refrigerant discharge temperatures, which may result in a breakdown of the oil present.

Two-stage compression can be accomplished by using two compressors and, in large installations, a rotary booster compressor is often used for the first stage. However, it is more likely that this is done in a duplex or compound compressor with some of the cylinders in a single machine forming the low-pressure (LP) stage and the remainder the high-pressure (HP) stage.

Manufacturers catalogues usually clearly define when two-stage operations should be used with their machines by only quoting capacities for single-stage machines within the limits of a single-stage operation.

Most fish-freezing operations involving evaporating temperatures of -35°C or lower, should have a two-stage compression.

The oil in a compressor does not remain entirely in the compressor sump, but is carried over with the refrigerant to the rest of the system. Oil separators are used with larger compressors to reduce, but not eliminate, this distribution of oil throughout the system, therefore, precautions still have to be taken to ensure that oil is returned to the compressor and not allowed to accumulate in other parts of the system, such as in the low pressure receiver or evaporator.

Once a system has been charged with oil and a balance maintained, with the oil leaving the compressor being matched by the oil returning, there should be little change in the oil level in the compressor sump. Some systems operating with ammonia refrigerant, however, may have oil drained from time to time from parts of the system and this has to be made up as necessary. Most other refrigerants, however, operate with a sealed system with no total loss of oil and the only requirement is the manufacturers' recommendations for oil changes. This usually only requires a change of oil shortly after commissioning and a routine change at the time of a major overhaul.

Any drop in the oil level therefore indicates a fault in the oil return system or in the operation of the machine.

Oil for refrigeration compressors has special properties for operating at low temperature, therefore, only the grades recommended by manufacturers should be used.

If the cost of a compressor or condensing unit is to be related to its refrigeration capacity, it is necessary to specify the following operational conditions:

- refrigerant used
- compressor speed
- compressor suction saturation temperature
- compressor delivery saturation temperature
- compressor suction superheat
- liquid subcooling at condenser outlet

A compressor cost can therefore only be determined when the exact operating conditions are known, and the unit identified after consulting manufacturer's capacity tables of the type shown in Figure 14.

General costs for a range of compressor sizes are therefore only listed for some arbitrary set of operating conditions and, with experience, this list may be interpreted to give a rough guide suitable for elementary costing at the planning stage.

The compressor prices in Figure 15 are for conditions which relate to likely fish-freezing and cold-storage operations but, when possible, budget prices should be obtained from the manufacturer or supplier when operating conditions are known.

3.1.2.3 Condensers: The condenser is the part of a refrigeration system where the heat taken in at the evaporator, together with the heat added by compression, is lost by the refrigerant to the surrounding air or water coolant.

(i) Air condensers

Air is a cheap collant, but since the rate of heat transfer from a surface to air is poor, air condensers tend to be large. Ambient air may also be at a high temperature and this will result in higher condenser pressures with added operational costs.

With smaller plants, the cost of operating with higher condensing pressures may not be prohibitive and the advantage of not having a piped water supply and waste-water requirement may be attractive. Air condensers are therefore widely used with smaller units.

One difficulty with air-cooled condensers is that they must be placed where cool air can be readily taken in and hot air leaving the condenser rejected.

Small domestic refrigerators and chill-display cabinets may have "static" air condensers which are usually finned pipe grids, fixed to the rear of the cabinet with natural circulation of air doing the cooling. These units must therefore be sited where air is allowed to circulate freely.

Air condensers with fan-assisted circulation can also be fitted to small chill cabinets, freezer cabinets or cold rooms as part of a self-contained unit and again they require correct sitting in order to give adequate ventilation of the condenser air.

Delv. gauge °C		Suction gauge (°C)					
		-40	-37.5	-35	-30	-25	-2
35	kcal	10.5	12.2	15.1	20.7	26.4	3
	kW	10.2	11.2	12.4	14.9	16.8	1
40	kcal	9.1	10.7	13.4	18.6	23.6	
	kW	9.8	10.9	12.2	14.9	16.0	
45	kcal	7.8	9.3	11.7	16.6		
	kW	9.3	10.4	11.8	14.8		
50	kcal	6.6	8.3				
	kW	8.9					
55	kcal						
	kW						

Figure 14 Manufacturer's compressor capacity table refrigerant 502

Notes:
1) Capacity in thousands of kcal/h
2) Power in kW absorbed at the compressor shaft
3) Capacity and power values given are for compressor speed of 1 450 rev/min
4) Compressor speed range 850-1 750 rev/min
5) Capacity at other speeds directly proportional to speed
6) Power at other speeds obtained by the percentages shown:

Speed (rpm)	1 000	1 250	1 450	1 750
Power (%)	93	97.5	100	103

7) Compressor suction superheat 80°C
8) Subcooling at condenser outlet 5°C

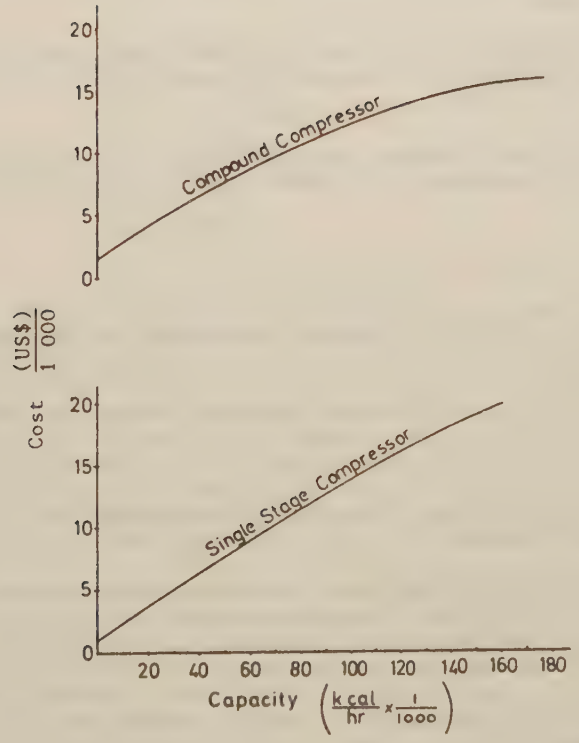


Figure 15 Compressor prices
(capacity at -35°C suction)
+35°C delivery)

Commercial and industrial applications with larger air condensers usually have the condensers remote from the compressor and outwith the building, usually on the roof. This, however, may result in long runs of delivery pipework and under certain circumstances this leads to difficulties with partial condensation before the condenser.

In some climates, seasonal changes in ambient air temperature may also give rise to problems. Air condensers are designed to match the highest ambient temperature likely and when it falls substantially below this value, the pressure at the expansion valve inlet may be insufficient to ensure the required flow of refrigerant. If this condition is likely, special precautions, such as reducing the condenser capacity or changing to another expansion valve, may have to be taken.

In spite of difficulties that may arise with air condensers and the extra costs involved, they are extensively used, particularly where there is no regular supply of cheap water of suitable quality.

Air-cooled condensers are usually rated for about 15°C temperature difference between the air and condensing temperature. Air velocities, measured as the average velocity over the condenser face area, are normally between 2.5 and 5.0 m/s. Heat transfer per unit surface area varies with a number of factors, but a value of 250 W/h per m^2 of extended surface would be typical.

Table 15 gives the likely physical dimensions and power requirements for a range of air condensers.

Table 15

Dimensions and power requirements for air-cooled condensers

Heat rejection $\frac{\text{kcal/h}}{1\,000}$ at 15°C temp. diff.	Fan power (fans x kW)	External dimensions (mm)			Costs (US$)
		A Length	B Breadth	H Total depth (incl. base)	
6.9	1 x 0.6	1 220	705	798	750
13.8	2 x 0.6	2 000	805	798	1 050
28.8	3 x 0.6	2 320	1 010	836	1 800
46.8	2 x 0.9	2 650	1 110	1 047	2 400
57.7	3 x 0.9	3 250	1 315	1 047	2 700
80.7	2 x 3.2	3 920	1 620	1 075	3 600
126.8	3 x 3.2	4 830	1 925	1 075	5 250
184.5	4 x 3.2	5 945	2 280	1 075	7 200
230.5	4 x 3.2	5 945	2 280	1 113	9 000

Note: The above ratings are for R12 with 3°C subcooling

It should be noted that correction factors may have to be applied depending on the refrigerant, and this is clearly stated in manufacturers' catalogues.

(ii) Water-cooled condensers

Water from a main supply is expensive and should only be used where the plant is small and air-cooling is impractical.

Water from natural sources, such as rivers, lakes and wells, requires to be of a suitable quality so that it does not corrode the condenser or foul the heat exchange surfaces. Chemicals, silt and biological contaminants such as algae are potentially damaging and maximum levels recommended by manufacturers may require the water to be filtered or treated chemically.

Uncertainty about the continuity of water supplies should also influence whether a water condenser is used, especially when it is considered that water supplies are likely to be more restricted during hot weather when the cooling demand is greatest.

The most popular type of water-cooled condenser is the shell-and-tube type where the water passes through the tubes. End covers are required to be removed periodically to clean the tubes, therefore, condensers should be sited to give access for this operation (Figure 16).

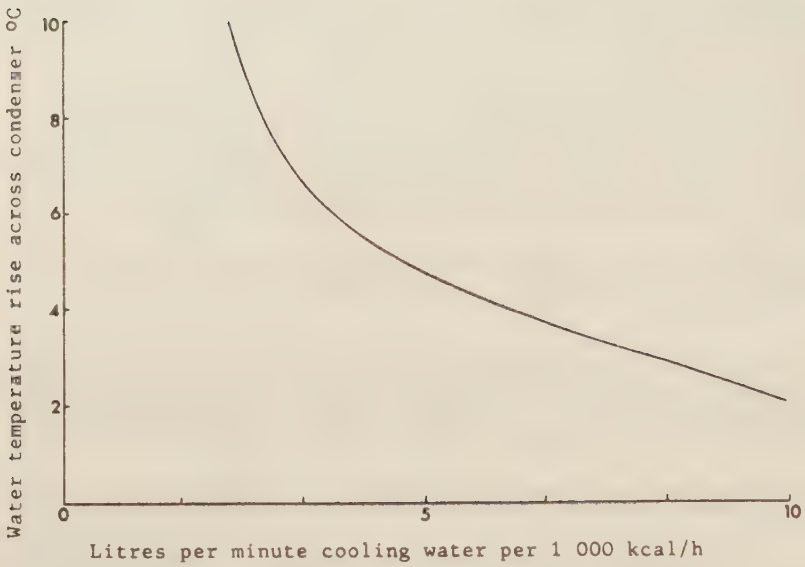


Figure 16 Water requirement of shell-and-tube condensers

Shell-and-tube condensers can either be mounted with the tubes horizontal or vertical and the available floor space and roof clearance may dictate which type is used.

Different flow patterns are also used and again the choice is mainly based on convenience. For instance, there may be a requirement for the water entry and exit connections to be at the same end of the tube.

Water-cooled condensers are more compact than the air-cooled due to the improved heat transfer between the water and the tube surface, which is about 15-20 times better than the air to surface heat transfer in an air-cooled condenser. Water-cooled condensers, however, do not always have fins to extend the heat transfer surface, therefore, the difference in size is not as striking as the difference in heat transfer rate would suggest.

If the temperature of the water supply is likely to change sufficiently to affect the performance of the thermostatic expansion valve or other refrigerant flow control, condenser pressure can be readily controlled by fitting a pressure-operated water valve which reduces water flow when the condenser pressure is reduced by circulating colder water than the design value.

Condensers are designed for a water flow rate of about 1.5 m/s through the tubes, and a temperature rise between inlet and outlet of about 5°C, but this may vary from one manufacturer to another, or it may be raised if water is not plentiful.

Table 16 gives the likely physical dimensions and water consumption for a range of shell-and-tube condensers.

Table 16

Shell-and-tube condensers

Capacity kcal/h / 1 000	Condenser dimensions		Water (kg/h)	Cost (US$)	
	Length (mm)	Diam. (mm)		(sw)	(fw)
2.1	760	90	420	252	157
10.7	760	115	2 140	732	480
21.5	760	165	4 300	1 065	765
43.0	1 524	165	8 600	1 725	1 215
64.4	2 286	165	12 880	2 250	1 530
107.4	2 286	216	21 480	2 850	1 860

Notes: (1) sw = salt water; fw = fresh water

(2) based on a 12°C temperature difference between inlet water and condenser saturation temperature, and a 5°C water temperature rise

(iii) Evaporative condensers

Air and water cooling are combined in an evaporative condenser with an advantage over air cooling, both in terms of heat transfer and lower condensing temperatures, and over water condensers with a greatly reduced water consumption.

In an evaporative condenser air is drawn upward over the condenser pipes and water is sprayed over the surfaces from above (Figure 17). Heat transfer results in the evaporation of some of the water flowing over the coils and the resultant water vapour is discharged to atmosphere with the exit air.

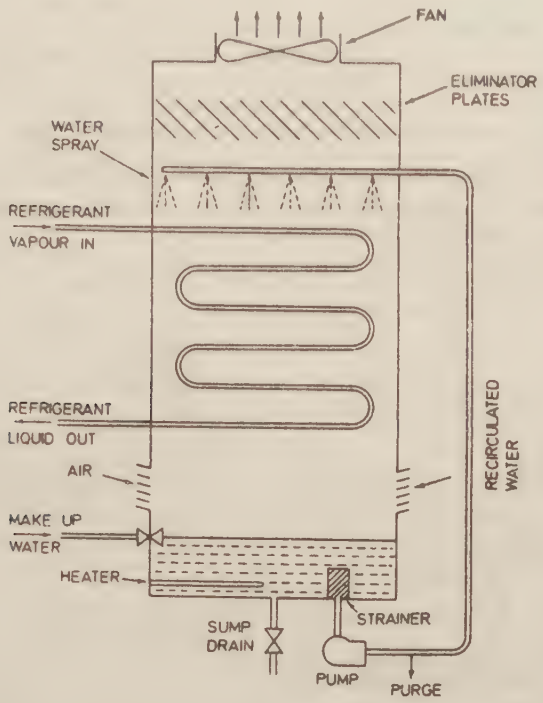


Figure 17 Evaporative condenser

As with air condensers, evaporative condensers require to be positioned so that air can be circulated freely and since the discharge air also contains a good deal of water vapour, the condenser must always be sited outside or the air ducted outside.

Theoretically, the water evaporated is approximately 2.7 kg/1 000 kcal of refrigeration effect, which is well below the nominal value of 200 kg required for a shell-and-tube condenser. Some water, however, is lost by small droplets being discharged with the air and a regulated overflow from the condenser reservoir is necessary to keep solids and other contaminants at a suitably low level of concentration.

Water consumption in an evaporative condenser in practice is, therefore, about 4-5 kg/1 000 kcal of refrigeration effect.

The likely dimensions, power requirements and water consumption for a range of evaporative condensers is given in Table 17.

(iv) Other condensing systems

Some of the benefits from different types of condenser can be combined when two or more of the basic systems of heat transfer are used.

A shell-and-tube condenser can be used with circulation of the cooling water if it is piped to either an evaporative cooler or air cooler at a suitably remote site (Figure 18). This offsets the need for a long run of refrigeration pipework, thus avoiding the associated refrigeration problems and, also, avoiding having high pressure pipes where they are vulnerable to damage or where leaks would create a safety hazard.

Table 17

Forced draught evaporative condensers

Capacity (kcal/h)	Fans (hp)	Pumps (hp)	Dimensions			Cooling water consumption (1/h)	Pump circulation rate (1/min)	Cost (US$)
			L (mm)	W (mm)	D (mm)			
12 000	1.0	0.5	2 120	914	1 000	40	63.6	2 550
15 000	1.0	0.5	2 120	914	1 000	50	63.6	2 590
30 000	1.0	0.5	2 527	914	1 000	100	63.6	2 650
60 000	2 x 1.5	1.0	2 426	1 828	1 302	200	118.2	2 850
90 000	2 x 3.0	1.0	2 490	2 742	1 600	300	205.0	3 150
150 000	2 x 3.0	1.0	2 972	2 742	1 600	500	205.0	4 050

Note: This table is based on a wet-bulb temperature of 27°C, a condensing temperature of 40°C, and an evaporating temperature of -40°C

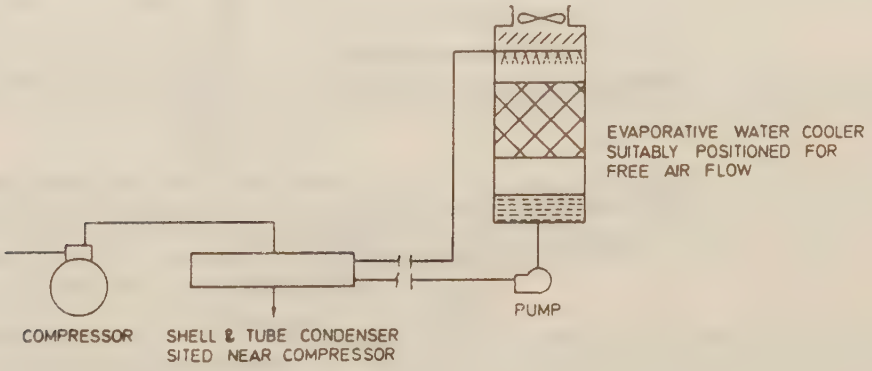


Figure 18 Condenser with remote water cooling

3.1.2.4 Evaporators: The word evaporator, by common use, now includes all coolers even when no evaporation takes place, such as in a system using a secondary refrigerant.

The evaporator is in effect the heat exchanger where heat from the product, or medium to be cooled, is transferred to the refrigerant.

Evaporators are made in many different forms depending on the refrigeration system and the application. In some cases they may form an integral part of the main equipment, such as the plates of horizontal and vertical plate freezers or the drum of a drum freezer. In other systems, the evaporator is an intermediate heat exchanger or liquid receiver, such as in flooded secondary and primary refrigeration applications. Many of these special cases are dealt with, or mentioned elsewhere, and therefore only the main type of evaporator used, which is for an air-to-refrigerant heat transfer, is considered in detail.

Evaporators for air-to-refrigerant heat transfer in air-blast freezers and cold stores are either made from plain pipe or finned pipe. Plain pipe evaporators are now little used for transfer of heat from air since they are more expensive, require a substantial supporting structure, take up more space and require a large standing charge of refrigerant. Plain pipes, however, may be used when heat-transfer from the pipe surface is high, such as from a refrigerant to a brine in a secondary system.

By far the most widely used are finned pipe evaporators which are built as compact units with fan-assisted circulation of air. Plate evaporators have also a limited application for air-cooling systems, particularly when the heat transfer requirement is not high and frosting of finned tube evaporators may be critical.

The materials used for evaporators must be compatible with the refrigerant and also with the environment in which they are sited. For instance, copper must not be used with R717 (ammonia) and special consideration should be given in a salt laden marine environment.

Finned tube evaporator units are made for wall, roof or floor mounting and the choice would depend on the convenience of placing them in any of these positions.

Defrost is an important consideration for evaporators operating below 0°C. Frost build-up on the heat exchange surfaces greatly reduces the heat transfer capability of the evaporator and this condition would become critical when the frost bridges the gap between adjacent fins and greatly reduces the surface area available for heat transfer.

In smaller units, electrical defrost is used with the heater elements built in as part of the unit. This is expensive and for larger units other methods are used, which may either be external or internal. Water or an anti-freeze solution can be periodically poured over the surface and drained away. This method, however, is not always convenient, especially when low temperature conditions have to be maintained at all times as they are in a cold store. Internal defrosting by means of hot gas redirected from the condenser discharge is more usual, but in order to do this effectively more than one evaporator must be operated from the same condensing unit and the evaporators defrosted in sequence. Reverse cycle defrosting, where the functions of the evaporator and condenser are reversed, is another method used with small units.

Fin-spacing is also an important aspect of design and a compromise has to be made between a close spacing giving a compact unit and a wider spacing which results in a larger unit but allows more frost to accumulate before a defrost is necessary. Fin spacings of 6, 8 and 12 mm are available in some standard evaporator ranges.

Each case must be considered individually but, in general, a spacing of 6 mm may be used when frost build-up is not critical, a spacing of 12 mm when there is likely to be a heavy accumulation of frost, and 8 mm for a compromise situation.

Another important consideration in selecting an evaporator is the characteristics of the fan. If the evaporator is free standing, as it is in an open cold store, and there is no need for the air to be circulated over a large area, propeller type radial fans may be used. These have simple blades shaped from flat, sheet metal and they are inefficient when there is a resistance to air flow.

In air-blast freezers and in cold stores where the air is required to be "thrown" over a distance, aerofoil blade fans are required. The blades are designed with a well shaped profile similar to the wing of an aeroplane and they are a good deal more efficient than the cheaper propeller type.

Standard ranges of wall/roof and floor mounted evaporators are listed in Tables 18, 19 and 20, together with their overall dimensions, weights and fan power requirements.

Table 18

Wall/roof mounted coolers/evaporators
- Propeller fans -

Refrigeration capacity (kcal/h)	Fin spacing (mm)	Fan power (W)	Air volume (m^3/s)	Air throw (m)	Dimensions			Approx. weight (kg)	Cost (US$)
					L (mm)	B (mm)	D (mm)		
344		1 x 7			525	375	180	6.5	350
686		1 x 15			690	375	180	8.0	420
1 615		2 x 15			1 120	375	230	15.5	450
2 017	6	1 x 125	.57	9.8	1 000	502	428	36.0	500
2 322	4								570
3 372	6	2 x 125	1.08	9.8	1 440	502	428	51.0	600
4 300	4								720
7 455	6	2 x 330	2.02	19.8	2 080	502	508	94.0	1 060
8 600	4								1 420
11 100	6	3 x 330	3.03	19.8	2 965	502	508	126.0	2 100
12 900	4								2 849

Table 19

Wall/roof mounted coolers/evaporators
- Aerofoil fans -

Refrigeration capacity (kcal/h)	Fin spacing (mm)	Fan power (W)	Air volume (m^3/s)	Air throw (m)	Dimensions L (mm)	Dimensions B (mm)	Dimensions D (mm)	Approx. weight (kg)	Cost (US$)
2 017	6	1 x 125	0.57	23	1 000	502	428	35	620
2 322	4								670
3 372	6	2 x 125	1.08	23	1 440	502	428	49	750
4 300	4								900
7 455	6	3 x 330	1.87	32	2 080	502	508	94	1 250
8 600	4								1 650
11 100	6	3 x 330	3.03	32	2 965	502	508	126	2 400
12 900	4								3 350

Table 20

Floor mounted coolers/evaporators

Refrigeration capacity (kcal/h)	Fan power (W)	Air throw (m)	Dimensions L (mm)	Dimensions B (mm)	Dimensions D (mm)	Approx. weight (kg)	Cost (US$)
9 000	2 x 820	27	2 413	1 320	1 016	295	6 200
14 000	2 x 1 050	27	2 743	1 320	1 220	490	6 450
25 000	2 x 1 350	27	3 200	1 320	1 625	886	7 800
53 000	3 x 3 060	40	4 673	1 420	2 083	1 955	12 300
64 000	3 x 4 100	40	4 673	1 420	2 438	2 364	14 400

Plate evaporators are either used in units consisting of a bank of plates on one framework and often incorporating a fan for air circulation, or as single plates which may be arranged against a wall or roof with natural circulation of the air. Types of plates used in plate evaporators are:

(i) steel with an embossed serpentine pattern for the circulation of the refrigerant;

(ii) pipe grids contained between sheet metal which is kept in contact with the pipe by evacuation of the air in the space between the sheets;

(iii) extruded aluminium plates of the type now extensively used in plate freezers.

3.1.2.5 Refrigeration, instrumentation and controls: In order to regulate the flow of refrigerant, maintain design operating conditions and allow equipment to be operated safely and economically, a number of controls are used with refrigeration systems.

The complexity of a control system usually relates to the size of the plant, ranging from no more than a capillary throttling device to regulate refrigerant flow in a small hermetic system to complex, computer-based control systems for the more recently installed large, multiple unit systems.

Some of the controls used for the size of plant more likely in the fishing industry are listed below. A brief indication is given of the requirement, function, whether spares are advisable and the likely cost.

(i) Pressure gauges

Pressure gauges are used to indicate plant-operating conditions and they are therefore useful for routine inspections and, also, when fault-finding. Gauges are normally positioned at the compressor

to indicate pressures on the high and low pressure sides of the system with additional gauges, as necessary, to indicate the intermediate pressure in a two-stage system and the delivery pressure of the compressor lubricating oil pump. An additional gauge may be used in a larger system to indicate the pressure at the evaporator and, also, the pump delivery pressure when a secondary refrigerant is used.

To cover all these requirements, three different pressure ranges may be required, and although they are not essential for the plant operation, spares should be available since a reliable gauge would help to reduce both operational and maintenance costs.

The cost of gauges will vary between US$ 5 and US$ 25.

(ii) Temperature gauges

Like pressure gauges, temperature gauges, or pocket thermometers, are used to monitor plant-operating conditions and to assist with fault-finding. Thermometers used with the refrigeration compressor are used to monitor temperatures at the same positions as the refrigerant pressure gauges since both readings are normally required to assess the plant-operating condition.

Additional temperature gauges are also helpful to measure cooling water temperature, the temperature of a secondary refrigerant or the temperature of a low pressure, primary refrigerant, liquid reservoir.

Dial gauges are also used to monitor the temperature in air-blast freezers, but for cold stores a recording thermometer is advisable since this information is often required for checking later.

Dial thermometers cost between US$ 15 and US$ 25.

Steam thermometers cost between US$ 3 and US$ 8.

Circular chart recorders cost about US$ 350.

At least two temperature ranges are required to cover all these requirements, and the availability of spares is not normally critical since thermometers can usually be interchanged without breaking into the system, or a hand-held thermometer, used in an appropriate way, can be substituted.

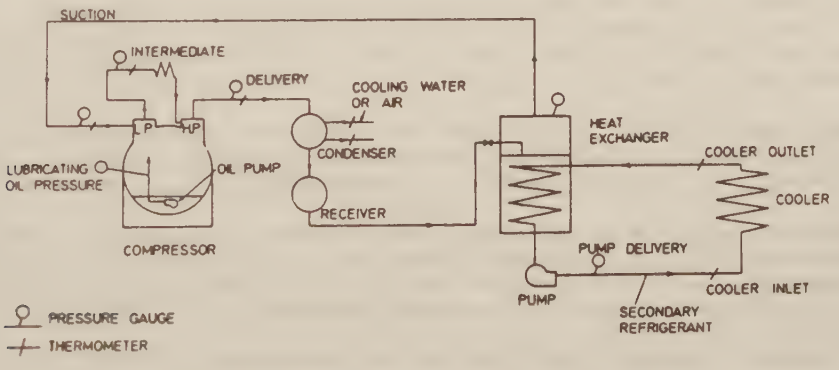


Figure 19 Pressure and temperature measurement

(iii) Refrigerant flow

Control of refrigerant flow is probably the most important control to be exercized in a refrigeration system. The following are four examples of control likely to be used:

(a) Hand expansion valve - A valve which accurately controls the flow of refrigerant to exactly match the refrigeration load. Hand expansion would only be used when the refrigeration load is constant or the inertia of the system means that changes would only be small and progress slowly; a large cold store with constant attendance is the type of application suited to this method.

Hand expansion valves are often fitted in parallel with other control devices so that they can be manually operated in the case of a failure. Cost US$ 30-60, depending on size.

(b) Thermostatic expansion valve - This is an automatic device which gives a modulated control of refrigerant flow and it is the most widely used method with a variety of individual designs to suit particular requirements. The valve senses pressure and temperature at the evaporator and uses the information to supply only sufficient liquid refrigerant to match the evaporator's requirement.

Thermostatic expansion valves (tev) are made in a wide range of sizes and models and the following list will, therefore, only give an approximate indication of the likely cost.

US$ 15 for tev with capacity of 1 000 kcal/h

US$ 50 for tev with capacity of 9 000 kcal/h

US$ 135 for tev with capacity of 90 000 kcal/h

US$ 150 for tev with capacity of 165 000 kcal/h

A spare valve should always be available, but the installation of a hand expansion by-pass can be used for a short time in an emergency.

(c) Low side level control - This can be a mechanical or electrical device which is used to control the level of liquid in the low pressure receiver of a flooded primary refrigerant system or the primary refrigerant level in the heat exchanger of a secondary refrigeration system.

The level control is essential to the operation of the system, therefore, a spare should be available or, depending on the type used, spares for the more vulnerable parts should be held. Cost US$ 200-350.

(d) High pressure level control - This is a mechanical or electrical device which is designed to maintain a constant level in a high-pressure liquid receiver. In a correctly charged flooded system this will ensure the correct level of refrigerant in the low-pressure receiver or heat exchanger. This type of control also ensures that the condenser is always empty of liquid refrigerant and thereby operates at its design capacity.

(iv) Safety devices

Safety devices come into two categories: those for protecting the equipment and those for the environment. Most small units operate without safety devices since replacement costs are low and irreparable damage less likely. Also, with smaller units, simplicity is always desirable. Larger units, however, from about 20 hp and upwards, would have one or more of the following devices:

(a) High pressure cut-out - This limits the pressure in the condenser and other parts of the high pressure side of this system thus avoiding the possibility of damage and overheating of the refrigerant oil. Cost US$ 15-75.

(b) Low pressure cut-out - This limits the minimum pressure at which the evaporator and other parts of the low pressure side of the system operate. Low pressures can be damaging to the machine and also give rise to excessive leakage into the system when the pressure is unnecessarily operated below atmospheric. Cost US$ 15-75.

(c) Oil pressure cut-out - This ensures that the compressor is not operated if for some reason lubricating oil is not being circulated at the required rate. Cost US$ 50-75.

(d) Motor overload - This device can protect both the drive motor and the refrigeration equipment if there is an excessively high load on the compressor, a blockage or ceasure.

(v) Capacity control

Capacity control of a refrigeration system can be achieved in many ways and the following list gives some of the methods likely to be used in fish freezing and cold storage:

Off-loading of cylinders in a multicylinder compressor

By-passing from delivery to suction at the compressor

On/off-cycling of the compressor by either a temperature or pressure-sensing device

Speed control of the drive motor either by electrical or mechanical means

A qualified person should be consulted on whether this requirement is necessary and on the choice of method used.

3.1.3 Liquified gases

Liquified gases are used almost exclusively for freezing smaller fish products in continuous freezers.

There are three liquified gases commonly used for this purpose:

Liquid nitrogen (N_2)

Liquid carbon dioxide (CO_2)

High purity R12 (liquid freon freezant or LFF)

Liquid nitrogen is sprayed over the product after it has been precooled or conditioned in the nitrogen gas during the early stages of freezing. Freezing by total immersion in liquid nitrogen cannot be used since it results in very quick temperature change in the product and this "thermal shock" results in physical damage.

Liquid carbon dioxide sprayed into the freezer results in the instantaneous formation of both solid and gaseous forms of CO_2. The solid form is deposited as a covering of "snow" on the surface of the product and sublimation of this "snow" at -78.5°C is responsible for most of the refrigeration effect.

Liquid freon freezant is either sprayed on the product or used with total immersion of the product, or a combination of both of these methods can also be used. In the case of an LFF system, unlike the others, the evaporated refrigerant is recondensed by means of a mechanical refrigeration system and reused with only a small loss of up to 3%.

Table 21 lists the physical properties and other data of the three refrigerants.

3.2 Specific Processes and Equipment

3.2.1 General

Freezers for fish and fish products can be divided into four main groups depending on the method of heat transfer used:

Air blast

Contact

Immersion

Liquified gases

The above main groups are dealt with later, where more specific details are given about their design and uses in the fishing industry. The following brief description therefore only gives a very broad outline of their main characteristics.

Air-blast freezers - widely used for nearly all fish and fish products since their main feature is a versatility to freeze products of all shapes and sizes. They are constructed for batch, continuous and batch/continuous modes of operation and therefore can be used for small operations as well as in large-scale production lines.

Contact freezers - this type of freezer has also many applications for fish-freezing with vertical plate freezers (VPF) and horizontal plate freezers (HPD) being the most familiar types. The main use of VPF and HPF is to freeze regular-shaped fish products such as blocks, packages and cartons.

Another type of contact freezer, which is a continuous process using a rotating drum, has also a limited use for freezing IQF products such as fish fillets.

Plate freezers are more familiar as units for batch freezing, but some designs for a continuous operation are available.

Immersion freezers - this type of freezer has now only a limited use and some of the applications, which previously used an immersion process, have changed to other freezing methods. Sodium chloride brine and salt/sugar solutions are two fluids which may be still considered for special purposes.

Liquified gases - these are used mainly where refrigerant supplies are readily available and are relatively cheap. The gases are used mainly for continuous freezing processes and nitrogen, carbon dioxide and a refined form of R12 are refrigerants which have been used for fish-freezing applications.

Table 21

Liquified gas refrigerants used in open systems

Data	N_2	CO_2	LFF
Chemical name	Nitrogen	Carbon dioxide	Dichlorodifluoromethane
Common name	Liquid nitrogen	CO_2 liquid	Liquid freon freezent Freon food freezant
Chemical formulae	N_2	CO_2	$C Cl_2 F_2$
Appearance liquid	Clear	-	Clear
Odour	None	Slight pungent	Faint ethereal, musty
Toxicity	Low	Low	Low
Density kg/m^3	784	464	1485
Specific heat liquid kJ/kg °C	1.04	2.26	.984
Latent heat kJ/kg	358	352	297
Total usable refrigeration effect - kJ/kg	690	565	297
Boiling point °C	-196	-78.5 (sublimation temperature)	-29.8
Thermal conductivity	.29	.19	.095
Comsumption/100 kg product frozen	100-300	120-375	1-3.0
Price 9/83 and quantity	$90/tonne 250 t/year	$128/tonne 250 t/year	$1,500/tonne in 67 kg cylinders

3.2.2 Air-blast freezers

3.2.2.1 Types: Air-blast freezers can be subdivided according to their mode of operation, method of loading and pattern of air flow. Some of the likely combinations can be derived from the block diagram in Table 22.

(i) Batch, continuous and batch/continuous

Batch freezers are more versatile than continuous, therefore, if a variety of products are to be frozen, a batch freezer may be selected. Batch freezers are also likely to be used for products with longer freezing times since with a batch freezer there is better utilization of floor space due to the multi-layer arrangement of loading. It is difficult to decide on an exact line of demarkation but freezing times longer than one hour would usually require a batch mode of operation. (See Figures 20, 21 and 22.)

Continuous freezers are best used for freezing individual portions, such as single fillets and small shellfish, such as peeled prawns and scallops. The main advantage in using a continuous freezer for these smaller and/or thinner products is that since they freeze quickly they will also thaw quickly and the delays that occur with a batch-freezing operation may be overlong. Continuous freezing allows quick handling after freezing and a quick transfer to the cold store.

Batch/continuous freezers are usually batch type freezers operated with trolleys which are loaded in sequence at fixed-time intervals rather than all at one time as in the truly batch freezer.

Table 22

Types of air-blast freezer

Type of Freezer	Method of Loading	Air Flow
Batch	Trolleys Pallets Shelves or Racking	Cross Flow Series Flow
Batch/Continuous	Trolleys Pallets	Cross Flow Series Flow
Continuous (In-Line)	Plain Belt Mesh Belt Link Belt	Cross Flow Series Flow
Continuous (Spiral)	Link Belt	Cross Flow Downward Flow
Continuous (Fluidised Bed)		Upward Flow
Continuous (Semi-Fluidised)	Mesh Belt Link Belt	Upwards and Cross Flow

The type of freezer used will depend on the specific requirements of each installation and the following brief notes will help with this choice

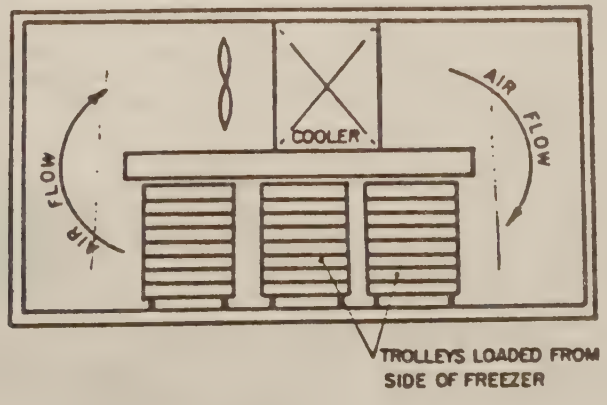


Figure 20 Batch air-blast freezer with side loading and unloading

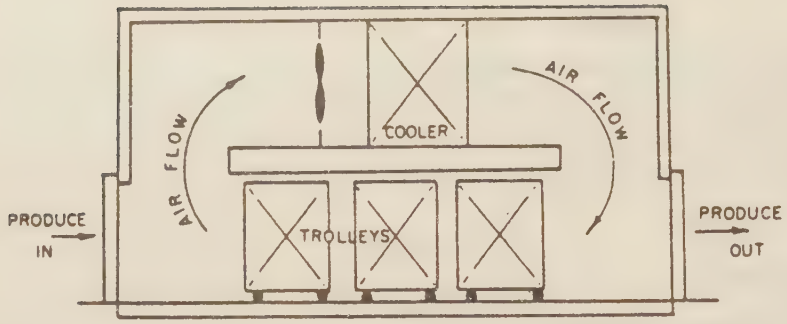


Figure 21 Batch-continuous air-blast freezer with counterflow air circulation

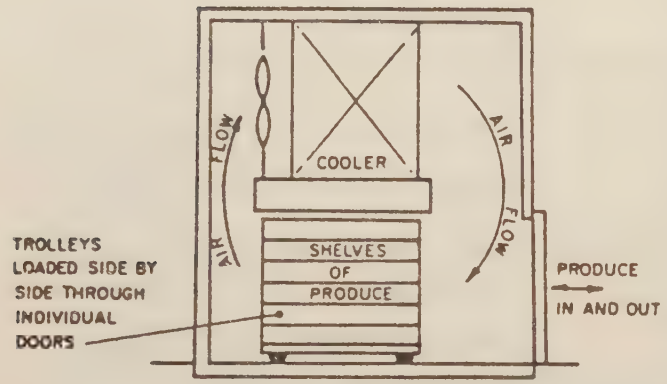


Figure 22 Batch-continuous air-blast freezer with crossflow air circulation

This allows the produce to be quickly loaded into the freezer rather than have delays while waiting for full loads. The number of trolleys and the loading interval are selected to ensure that when the freezer is fully loaded a new trolley will be exchanged with one which has been in for the necessary freezing time and, thereafter, a one out and one in system is operated. This loading arrangement also ensures that the refrigeration demand is more uniformly spread than would be the case for a batch freezer (Figure 23).

A batch-continuous freezer layout and airflow arrangement should be designed to ensure that a new load of warm fish is not placed upstream of a partially frozen load.

(ii) Trolleys, pallets, shelves

Trolleys are more mobile but take up more space on the factory floor. Pallet loads can be moved directly from the freezer to a cold store for temporary storage without the need for taking expensive equipment out of service.

Fixed shelves within the freezer are not recommended since the freezer door must be left open during loading. This may take a considerable time and result in an unnecessary high ingress of heat and water vapour with the air entering the freezer. With a fixed shelf arrangement some of the air-blast freezer's versatility will also be lost.

(iii) In-line or spiral continuous freezers

Spiral freezers are designed to reduce the floor space requirement of the freezer but they, in turn, require a higher roof clearance and in some cases this may be equally critical. Spiral freezers also tend to distort the shape of some products due to the curvature of the belt path. In-line freezers have been built with a multi-belt operation in order to reduce the floor space (Figure 26). Transfer of partially frozen fish from one belt to another, however, may be difficult and result in breakage or distortion of the product. This transfer, however, is achieved with some degree of success in a semi-fluidized freezer with some products by ensuring that the wet product does not adhere to the first belt (Figure 27).

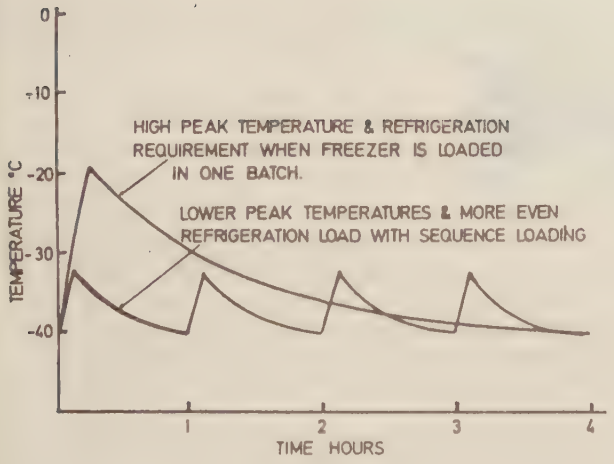


Figure 23 The effect on temperature and refrigeration capacity when loading a batch air-blast freezer

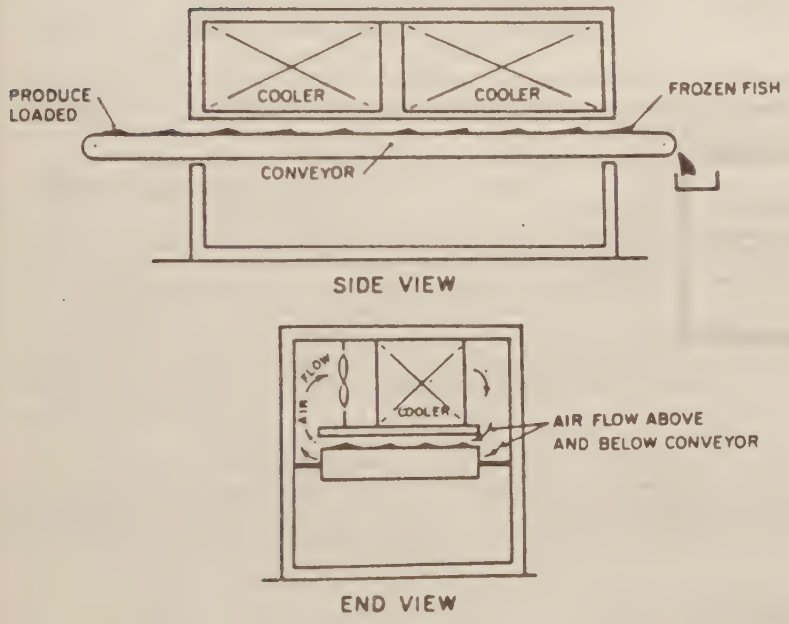


Figure 24 Continuous belt air-blast freezer with crossflow air circulation (also constructed with countercurrent series flow air circulation)

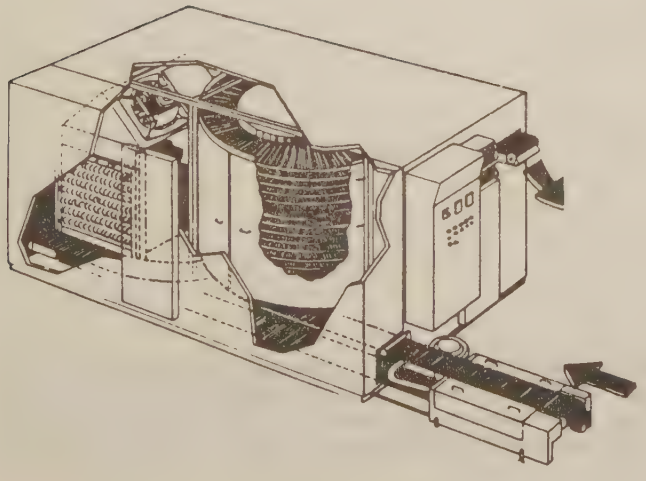


Figure 25 Continuous air-blast freezer with the belt arranged in a spiral

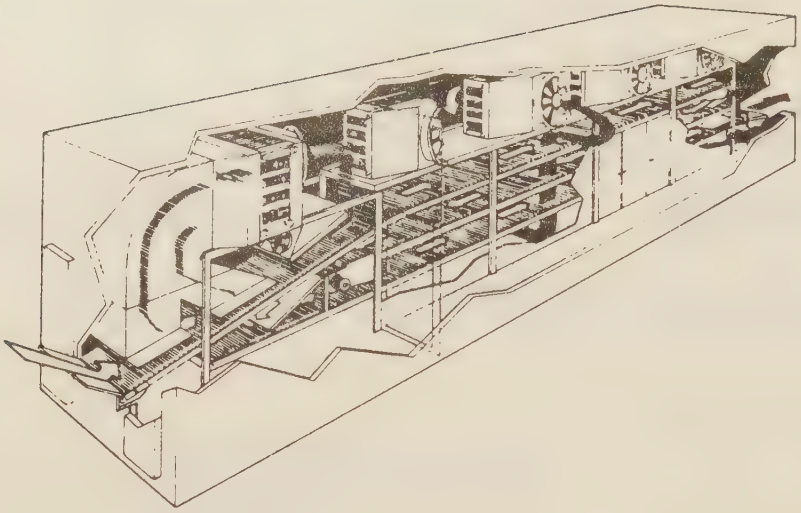


Figure 26 A triple-belt air-blast freezer

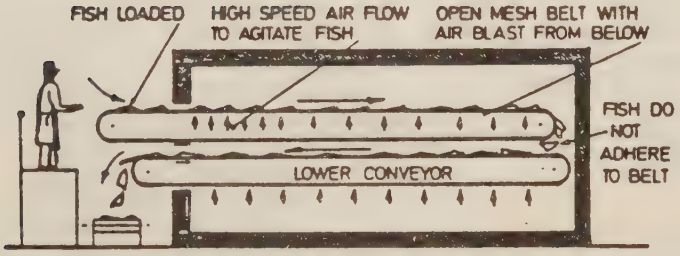


Figure 27 Semi-fluidized flow freezer with double belt

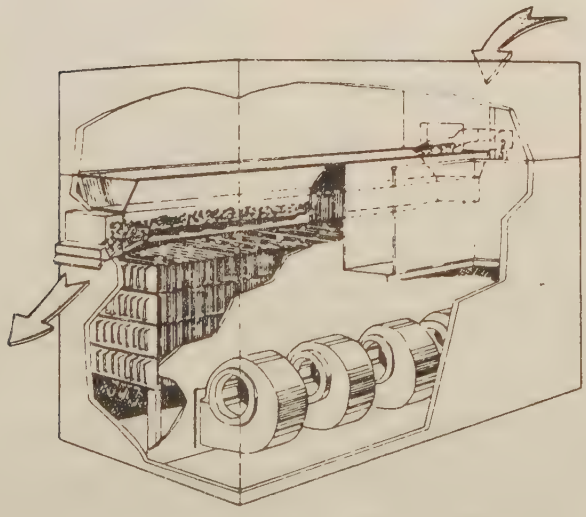


Figure 28 A fluidized flow air-blast freezer

(iv) Mesh, link or flat belts

Mesh and link belts can be used with fish which are unskinned, if the skin is arranged to be in contact with the belt. Freezing skin-off fillets and other fish and fish products, which must be frozen with the flesh in contact with the belt may, however, prove to be difficult, with damage to the product and loss of yield due to breakage when releasing the frozen product. Flat belts made

from sheet stainless steel are now used with in-line freezers, and most products can readily be released without damage. Also, with a flat belt, particularly delicate products can be released by defrosting the belt at the exit of the freezer by spraying the underside of the belt with water.

(v) Crossflow and series flow

Whether one pattern of flow or another is used depends mainly on the configuration of the freezer and, before deciding on this aspect and other features of the design and layout, the following should be considered:

- total volume of air flow
- temperature rise of the air over the product
- flow only from colder to warmer products
- large-face area of the cooler required for minimum frost interference
- pressure differences within the freezer in relation to doors and openings
- pressure drop around the circuit and the effect on fan power

A knowledge of both the intended freezer operation and the elements of good engineering and heat transfer practice will, therefore, be required before a final decision is taken.

3.2.2.2 Costs: Only a rough guide can be given on the cost of air-blast freezers since, unlike other types of freezer, it is the exception rather than the rule to buy them as standard designs from an established range of sizes, particularly in the case of batch freezers. Batch air-blast freezers are usually built on site to suit individual requirements and local costs may, thereby, account for a good proportion of the total cost.

Some guidance on costs, however, is presented in graphical form in Figures 29-33. In these costings the refrigeration machinery is included, but this may not always be the case.

Care should always be taken to ascertain what the cost includes when making comparisons between freezers.

3.2.2.3 Air speed: A compromise has to be made in the design air speed of an air-blast freezer since high air speeds and good heat transfer also mean higher costs. Figure 34 shows a typical relationship between air speed and freezing time with long freezing times at low air speeds and little to be gained if higher air speeds are used. Air speed affects the surface heat transfer only, therefore, the influence on overall heat transfer depends on the relationship of this surface effect to the heat transfer, through the product and packaging. Improved surface heat transfer would, for instance, have less effect on the freezing time of thicker products or products which are wrapped before freezing.

Experience has shown that an air speed of 5 m/s is a good average value for batch air-blast freezers and this should ensure that there is an effective air speed throughout the freezer space. With longer freezing times, such as in freezers designed to freeze thicker products overnight, lower air speeds may be justified, but it is unlikely that this air speed would be less than about 3 m/s.

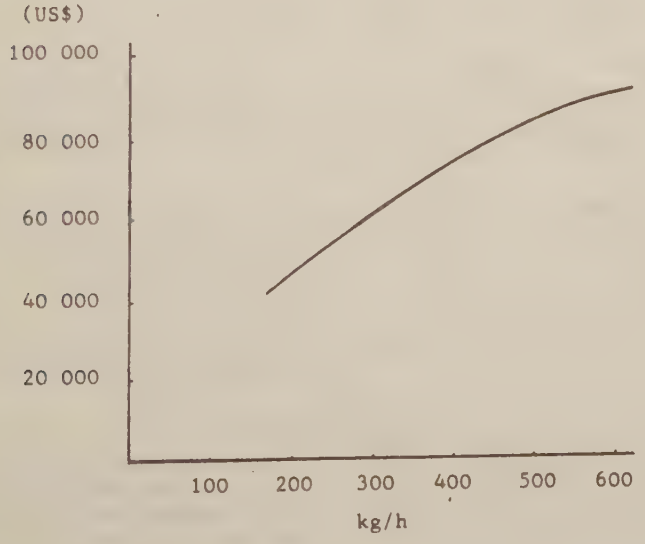


Figure 29 Batch freezers (including refrigeration)

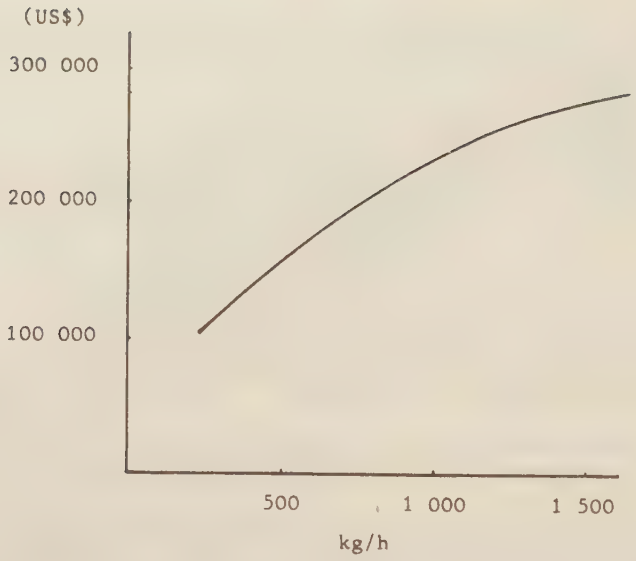


Figure 30 Continuous spiral freezers (including refrigeration)

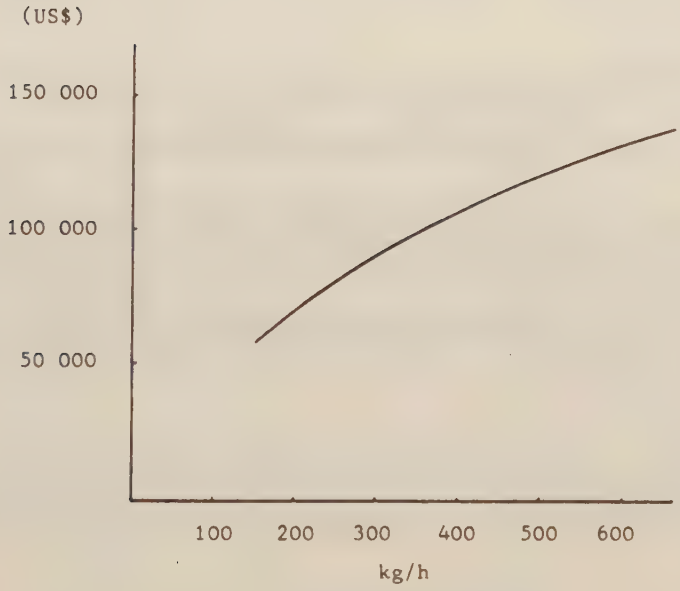


Figure 31 Continuous single-mesh belt in-line freezers (including refrigeration)

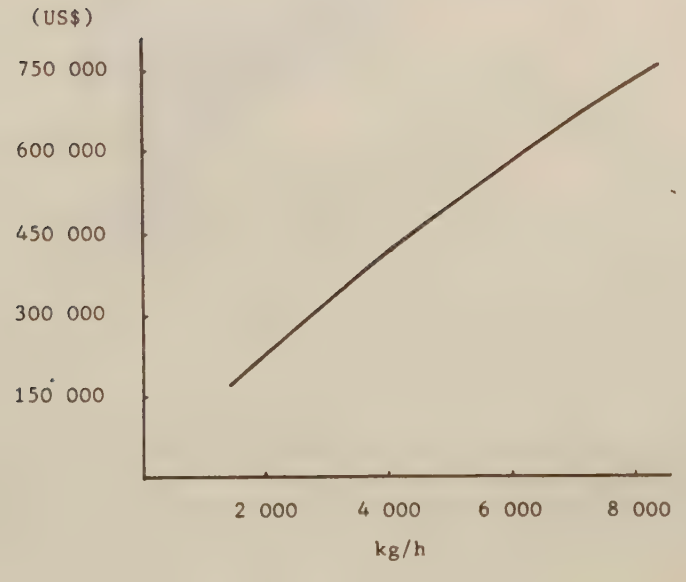


Figure 32 Fluidized freezers (including refrigeration)

Note: The above costs were for a PEA freezing operation. Although there will be some difference when freezing small shrimp, the costs will be of much the same order of magnitude.

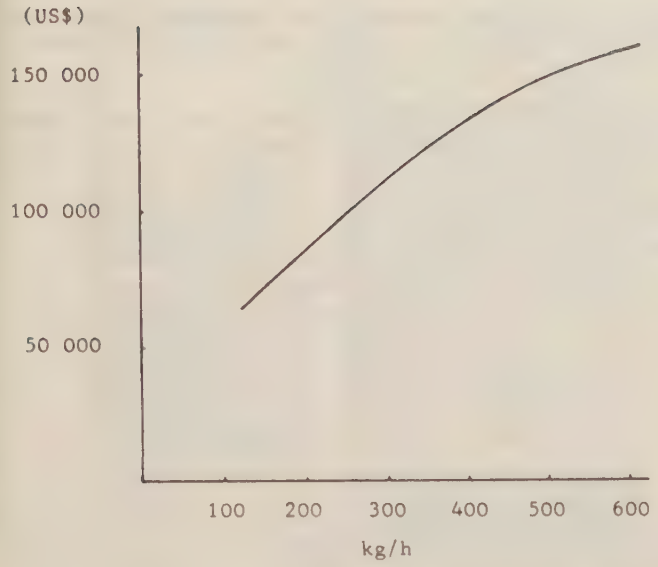


Figure 33 Flat belt continuous in-line freezer (including refrigeration)

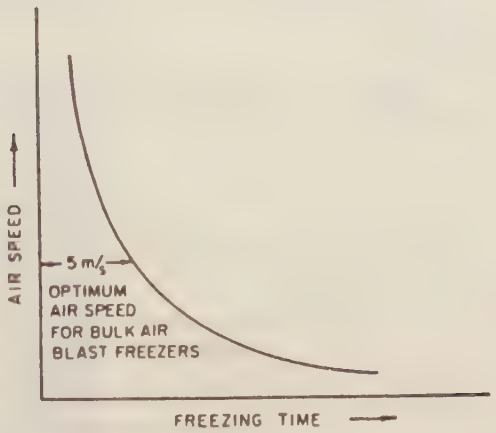


Figure 34 Variation of freezing time with air speed in an air-blast freezer

Since continuous air-blast freezers can take up a good deal of floor space, there is an incentive to improve the heat transfer and reduce the freezer size by using higher air speeds.

An air speed of 10 m/s has been used in a continuous air-blast freezer and since the type of product frozen is either small or thin, this higher air speed has a significant effect on the overall heat transfer. High air speeds need only exist in the working section of the freezer, therefore, an arrangement such as that shown in Figure 24 will ensure that the fan power is not excessive.

Even in well designed freezers the heat introduced by the fan may account for 20-25% of the refrigeration requirement and in a badly designed freezer fan heat may even exceed the heat to be removed from the product.

3.2.2.4 Operating temperature: The design temperature of an air-blast freezer should be related to the temperature of the cold store to which the product is transferred after freezing. Good freezing practice should ensure that the product is frozen down to an average temperature equal to the intended storage temperature, and in order to achieve this, the air temperature in the freezer should be at lease 5°C lower. For example, with a storage temperature of -30°C, the associated air-blast freezer will require to have an air temperature of -35°C and for -25°C storage, the air temperature should be -30°C.

Lower operating temperatures may occasionally be justified in order to achieve quicker freezing times, but this adds to the cost of freezing and there may be problems with the leaks into the refrigeration system due to the low pressures associated with the low temperatures.

3.2.2.5 Floor area: The floor area required for a freezer will obviously depend on its freezing capacity, but it also depends on the type of the freezer and the product to be frozen.

Bigger freezers tend to use space more economically as can be seen from the following examples of batch freezers for freezing trays of fish on trolleys:

Capacity (kg/h)	Floor space (m^2)
100	10
1 000	50

A slow freezing product will require a larger freezer than a faster product and this is illustrated by the following comparison:

Freezer	Capacity (kg/h)	Freezing time (h)	Freezer load (kg)
A	100	1	100
B	100	2	200

Both freezers have the same capacity, but due to the longer freezing time in B, the freezer requires to hold double the load of freezer A which will be loaded and emptied twice during the two-hour period.

A comparison is made between the floor area requirements of different types of air-blast freezer in Table 23. All freezers have a capacity for freezing 700 kg/h of IQF fillets.

Table 23

Floor space requirement of air-blast freezers

Type of freezer	Floor area (m^2)
Continuous in-line freezer, 10 m/s air speed	215
Continuous in-line freezer, 5 m/s air speed	260
Batch freezer, 5 m/s air speed	85
Continuous spiral freezer, 5 m/s air speed	100
Fluidized bed freezer[a/]	170

a/ Only likely application would be for cooked, shell-off small shrimp and other products of similar nature

All space requirements quoted in Table 23 are for the freezer cabinet only, but other space requirements must also be added.

Only in very small freezers will the refrigeration machinery be incorporated as part of the freezer unit, positioned either above or below the freezer cabinet. Machinery is therefore located outwith the working area and preferably in a separate room.

Floor space is required for loading and unloading the freezer, and space may also be required for a complete spare set of trolleys or pallets so that they can be loaded and waiting for the next freezing cycle.

Batch freezers are often built on site as an integral part of the building, but previously constructed or free-standing freezers should be left with a space around them for inspection and maintenance of the insulated structure.

Space may also be required for releasing frozen fish from trays or frames and, in turn, space and facilities for cleaning and storage of the trays will also be required.

The space requirements of a freezer may therefore exceed the space occupied by the freezer cabinet and it is this total space requirement that should be used in making comparisons and calculations. With the other space requirements taken into account the relationship between the freezers shown in Table 23 may therefore be totally different.

3.2.2.6 Freezing time and cycle time

Freezing times are determined by the size, shape and packing of the product together with the temperature and air speed in the freezer. The freezing cycle depends both on the freezing time and the time taken to load and unload the freezer.

If other considerations permit it, freezing cycle times should be selected to give optimum use of the freezer. For instance, a change in product thickness may allow the cycle time to fit exactly into a working day and thus the freezer will be fully utilized, as shown in the following comparison:

Working day (h)	Starting and stopping (h)	Time for freezing (h)	Cycle time (h)	Cycles	Utilization (%)
8.5	1	7.5	2.5	3 x 2.5	100
8.5	1	7.5	3.0	2 x 3	80

3.2.3 Horizontal plate freezers

3.2.3.1 General: Horizontal plate freezers (HPF) are used for freezing regular shaped packs of fish. The product is frozen in cartons, freezing frames or lidded trays which make direct contact with the plates through which the refrigerant is circulated.

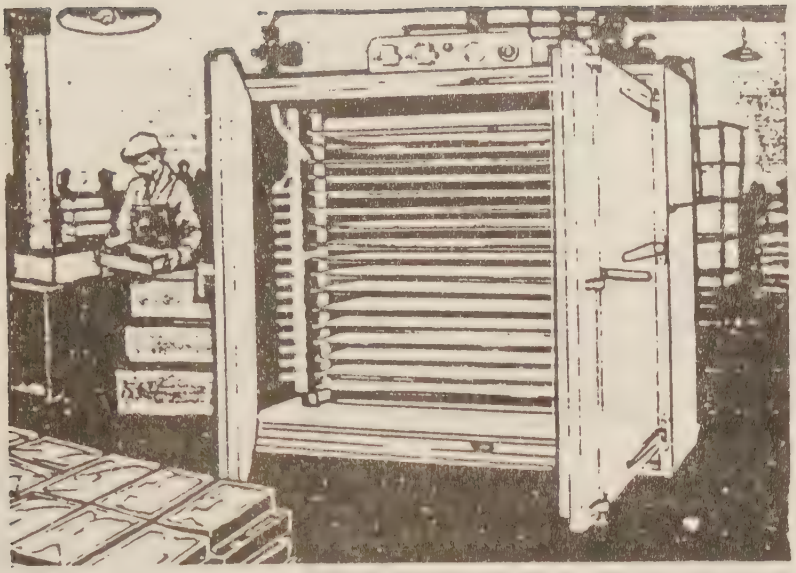


Figure 35 Horizontal plate freezer

The horizontal plates are pressed together to a predetermined spacing, set by the product thickness, and the contact pressure is maintained by a hydraulic device during the freezing process.

The bank of freezer plates forming the unit is normally contained in an insulated enclosure which is lined internally and externally with galvanized or coated metal sheeting. Access to the freezer stations is either by means of vertically-lifted curtains or doors, at the front and rear.

The capacity of a HPF unit depends on the product thickness, plate size and the number of stations and, within the extreme limits of the various combinations available, freezers can be constructed to suit individual requirement.

Plate sizes may differ between one manufacturer and another and each may only offer a choice of three standard sizes for their complete range of freezers.

A manufacturer may have a range of freezer units with up to 20 stations but, obviously, the wider the spacing between plates the fewer would be the maximum number of stations in order to keep the freezer height reasonable.

When selecting the space required between plates, it is usual to have the maximum plate opening 25 mm more than the thickness of the product to allow easy loading. (Tables 24 and 25.)

When calculating the weight that can be frozen in a HPF the number of packages and the weight of fish contained in each package have to be taken into account.

Plate dimensions and package sizes should be matched to avoid excessive waste of potential freezing space and it is usual to achieve about a 75% plate coverate in practice.

Although freezers can be supplied with wider plate spacings, it is usual to freeze fish products in packages, trays or forming frames with a depth not greater than 50 mm to 75 mm.

Individual calculations will require to be made for each application to obtain accurate figures but an indication of the loading of individual freezer stations is given in Table 26 for guidance.

The use of freezer trays and freezer frames (Figure 36), depends on the type of product to be frozen. Cartons, other containers and blocks of fish with only nominal dimensions are normally frozen in trays. For the production of blocks with a requirement for precise dimensions, freezing frames are necessary, but again these may be placed on a base tray to facilitate loading and unloading.

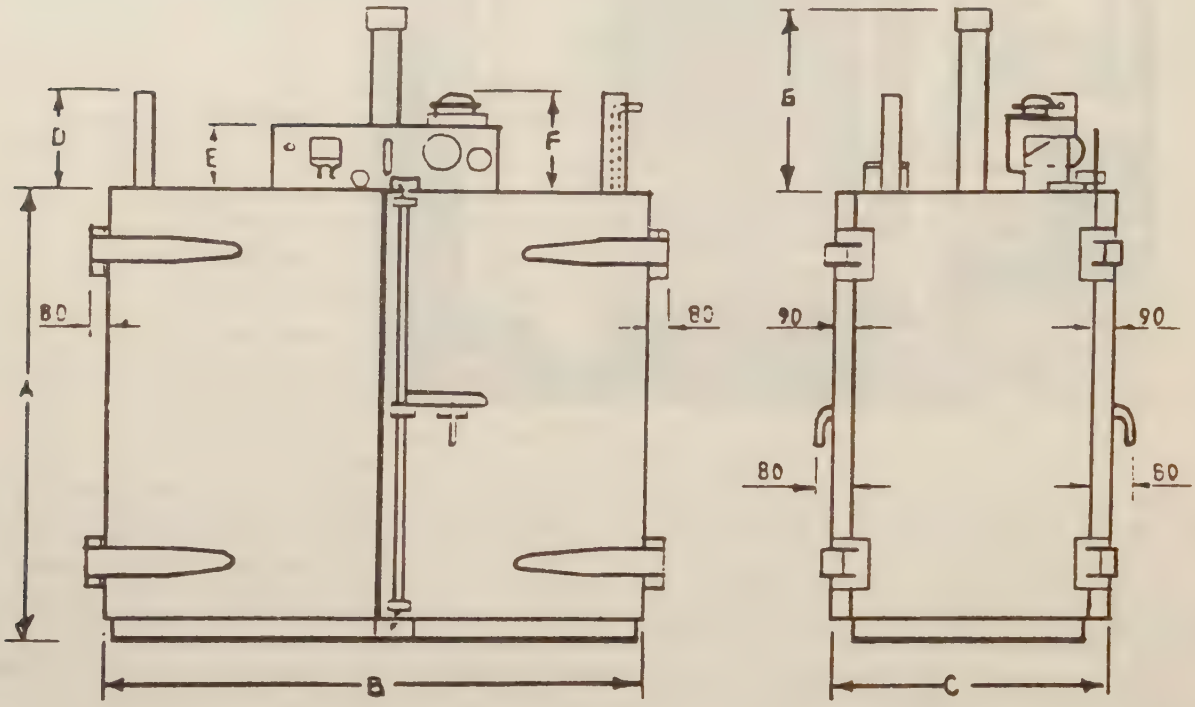
Refrigeration systems used with HPF are:

(1) . Pump circulation system with a primary refrigerant

(2) Pump circulation system with a secondary refrigerant

Table 24

Dimensions and shipping weights for horizontal plate freezers
(See Table 25 for plate sizes)



No. of stations	Dimensions (mm)							Weight (kg)
	A	B	C	D	E	F	G[a/]	
5	1 460	2 360	1 400	350	200	420	425	1 840
6	"	"	"	"	"	"	"	1 890
7	"	"	"	"	"	"	"	1 940
8	1 880	"	"	"	"	"	640	2 020
8	"	"	1 650	"	"	"	"	2 420
9	"	"	1 400	"	"	"	"	2 100
9	"	"	1 650	"	"	"	"	2 550
10	"	"	1 400	"	"	"	"	2 160
10	"	"	1 650	"	"	"	"	2 670
11	"	"	"	"	"	"	"	2 800
12	2 155	"	"	"	"	"	"	2 930
12	"	2 790	"	"	"	"	"	3 250
13	"	2 360	"	"	"	"	"	3 040
13	"	2 790	"	"	"	"	"	3 400
14	"	2 360	"	"	"	"	"	3 270
14	"	2 790	"	"	"	"	"	3 580
15	2 580	2 360	"	"	"	"	"	3 400
15	"	"	"	"	"	"	"	3 630
16	"	"	"	"	"	"	"	4 130
17	"	"	"	"	"	"	"	4 210
18	"	"	"	"	"	"	"	4 290
19	"	"	"	"	"	"	"	4 370
20	"	"	"	"	"	"	"	4 450

a/ For shipping, the hydraulic cylinder can be removed. Maximum shipping height is therefore given by A and F

Table 25

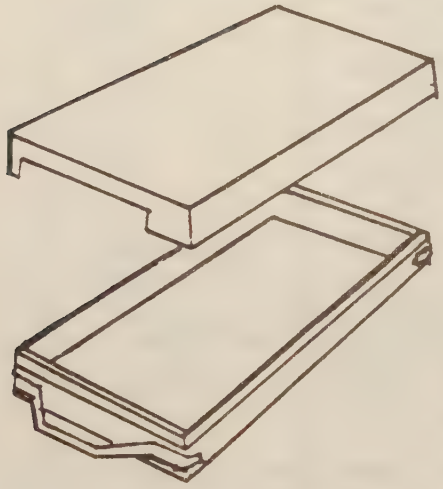
Horizontal plate freezer - plate sizes and openings

No. of stations	Dimensions (mm)		
	Plate sizes	Plate openings (max)	(min)
5	1550 x 820	108	38
6	" "	95	38
7	" "	90	38
8	" "	108	38
8	1550 x 1120	108	38
9	1550 x 820	100	38
9	1550 x 1120	100	38
10	1550 x 820	94	38
10	1550 x 1120	94	38
11	" "	89	38
12	" "	102	38
12	1930 x 1120	102	38
13	1550 x 1120	90	38
13	1930 x 1120	90	38
14	1550 x 1120	83	38
14	1930 x 1120	83	38
15	1550 x 1120	90	32
15	1930 x 1120	90	32
16	" "	86	32
17	" "	82	32
18	" "	79	32
19	" "	75	32
20	" "	70	32

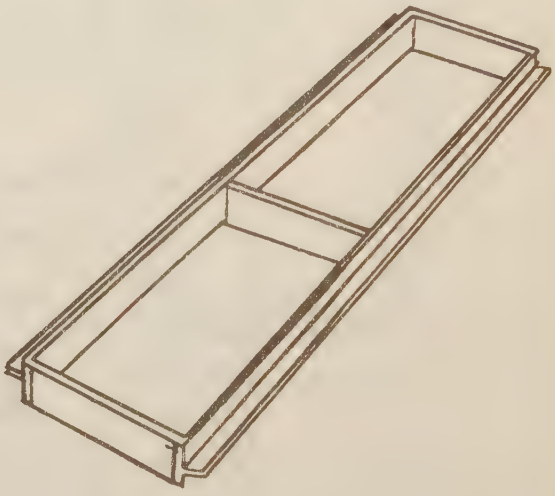
Table 26

Horizontal plate freezers
Average net weight of product per station (kg)

Product and thickness (mm)		Standard plate dimensions (mm)		
		1 550 x 820	1 550 x 1 120	1 930 x 1 120
Whole fish	50	45	59	71
	75	68	88	106
Fish fillet	50	59	77	95
	75	88	116	143



General purpose metal freezer tray
Trays are normally designed to hold a number of packages or cartons and dimensioned to achieve optimum use of the freezer plate area



Horizontal plate freezer frame
Freezer frames may be constructed for one or more packages. The double frame shown above has strengthened T-section sides but flat sides are also widely used

Figure 36

(3) Gravity feed flooded system

(4) Direct expansion system

The pump circulation system is recommended for large capacity freezers or multiple freezer installations in order to achieve a good, uniform heat transfer in all freezer plates. For secondary pump circulation systems calcium chloride brine or trichloroethylene are the most commonly used refrigerants, but due to the higher capital cost of this system it is usually confined to large marine installations.

The gravity feed, flooded system is the most widely used for medium and large, single unit freezers. The low temperature reservoir vessel is mounted directly above the freezer to give a compact and efficient layout and operation.

Direct expansion systems are more appropriate for smaller freezer units where there will be less difficulty in achieving good refrigerant distribution and hence uniform freezing.

Table 27

Pump circulation rates for horizontal plate freezers

Refrigerant	Circulation rate (litres/h/1 000 kcal)
Ammonia	67
Refrigerant 12	251
Refrigerant 22	196
Refrigerant 502	251
Calcium chloride brine	435
Trichloroethylene	570

Accurate freezing times are essential for calculating the capacity of a freezer and the times used should preferably be measured freezing times obtained by freezing samples of the product under the intended operating conditions. Before using freezing times from other sources, reference should be made to sources giving more information on this subject since the freezing time can vary considerably depending on a number of factors.

Table 28

Horizontal plate freezer - approximate freezing times
(Pump circulating system evaporating at -34°C)

Product	Product thickness and freezing times			
	50 mm	62 mm	76 mm	100 mm
Fish fillets	60 min	75 min	105 min	165 min
Whole fish	75 min	90 min	120 min	180 min
Herring/Sprat	60 min	75 min	110 min	170 min
Shrimps in cartons	90 min	135 min	160 min	230 min

Table 29

Horizontal plate freezer - approximate freezing times
(Gravity feed flooded system evaporating at -34°C)

Product	Product thickness and freezing times			
	50 mm	62 mm	76 mm	100 mm
Fish fillets	75 min	110 min	145 min	195 min
Whole fish	90 min	120 min	150 min	210 min
Herring/Sprat	73 min	115 min	150 min	210 min
Shrimps in cartons	110 min	170 min	200 min	270 min

Defrost time and the time taken to load and unload the freezer also have to be taken into account when calculating the freezing capability.

On most installations it is only necessary to defrost once per day if no liquid is spilled on the surface of the freezer plates. The daily defrost then may be achieved overnight by leaving both doors open although, on occasion, some assistance may be given by hosing the plates with clean water.

If it is necessary to operate with a quick defrost between each freezer load, it may be necessary to have a built-in defrost system. A quick defrost may also be required if the freezer was used 24 h/day with only 1-2 h allowed for defrost and cleaning.

Assuming trays are preloaded and a full load is available, the combined loading and unloading time for each HPF cycle under ideal conditions should be about 15-20 min for medium sized freezers and proportionally shorter or longer for other sizes.

3.2.3.2 Selection: Before any selection can be made, basic information must be established

(i) Quantity of frozen product required per day

(ii) Thickness of product

(iii) Nature of product

(iv) The refrigeration system to be used

The number of cycles per day is:

$$\frac{\text{Operating time/day}}{\text{Freezing time + loading/unloading time}}$$

When selecting horizontal freezers for 24-h operation, allow 1-2 h less for defrost and cleaning.

The weight of product to be frozen during each cycle:

$$\frac{\text{Total daily throughput}}{\text{Number of cycles/day}}$$

The number of stations required:

$$\frac{\text{Weight of product frozen/cycle}}{\text{Weight load/station}}$$

The nearest whole number is taken. Should this figure be above the maximum number of stations available, divide so that suitable equally stationed freezers can be selected.

3.2.3.3 Refrigeration capacity: Calculate the total heat content of the product and add 20%.

Refrigeration capacity required:

$$\frac{\text{Total heat/kg x weight in freezer}}{\text{Freezing time}} \times 1.2$$

Where multi-installations are selected, the above capacity may be reduced 5% for each additional equally sized freezer up to a maximum of 15%, provided the loadings are staggered.

Evaporating temperature to be used with the above refrigeration capacity is given in Table 30.

Table 30

Evaporating temperatures of horizontal plate freezers

Cycle	Evaporating temperature	Approximate evaporating range
Pump circulation	-34°C	-32/-42°C
Gravity	-34°C	-32/-42°C
Direct expansion	-30°C	-20/-27°C
Secondary pump	-34°C plus temperature drop across secondary cooler	

The refrigeration requirement calculation for an HPF must take into account allowances for the type of product, initial and final temperatures, trays, frames and packaging, insulation heat gains, pump energy input and other possible factors. In the absence of detailed information a value of 115 kcal/kg can be used with some assurance for chilled fish frozen without added water. Added water will increase this value by 101 kcal/kg of water added.

Some other recommended values are given for typical fish products in Table 31.

Table 31

Horizontal plate freezer refrigeration requirements

Product	Refrigeration requirement (kcal/kg of product)
Fish fillets in trays, 50 mm thick	117
Whole fish in trays, 75 mm thick	105
Prawns in cartons in trays 63 mm thick	103

Notes: (i) Product initial temperature is 10°C and final temperature approximately -30°C

(ii) Capacity is for product only, excluding added water

Selection example

A customer requires to freeze 30 t of fillets in a 24-h working day. The fillets are to be frozen in 50-mm thick blocks and the refrigeration plant is to operate with an ammonia pump circulation system. The initial product temperature is 10°C and the final equilibrium temperature -30°C.

Freezing time	1 h
Weight loading/station (1 930 x 1 120-mm plates)	100 kg
Number of cycles/day	$\frac{24 \text{ h}}{1 \text{ h} + 15 \text{ min}}$
	corresponding to 19 cycles
	say, 18 cycles allowing 1½ h for defrosting
Weight frozen each cycle	$\frac{30\,000 \text{ kg}}{18 \text{ cycles}}$
	corresponding to 1 666 kg
Number of stations required	$\frac{1\,666 \text{ kg/cycle}}{100 \text{ kg/station}}$
	corresponding to 17 stations

The freezer selected will therefore be one 17-station freezer fitted with 1 930 x 1 120-mm plates.

At this point the maximum plate openings must be checked to assure that a clearance of at least 25 mm is available from a standard range. Should a greater opening be necessary, then a purpose-built unit will be required.

Refrigeration capacity $\frac{117 \text{ kcal/kg} \times 1\,666 \text{ kg}}{1 \text{ h}}$

corresponding to 194 922 kcal/h

If 10% water was added this would increase by 1 666 kg x 0.1 x 101 kcal/kg,

corresponding to 16 827 kcal/h

Refrigeration requirement 194 922 + 16 827 = 211 749 kcal/kg

Table 32

Cost of horizontal plate freezers

Description	No. of stations	Plate size (mm)	Cost (US$)
Freezer only	5	1 550 x 820	14 250
Freezer only	20	1 930 x 1 120	27 750
Self-contained unit including refrigeration	5	1 550 x 820	28 500
Self-contained unit including refrigeration	7	1 550 x 1 120	32 250

3.2.4 Vertical plate freezers

3.2.4.1 General: The vertical plate freezer (VPF) is ideally suited for bulk freezing of fish, and although originally designed for freezing fish at sea, it is now also used extensively on land, mainly for freezing seasonal fish which are frozen in bulk for processing throughout the year.

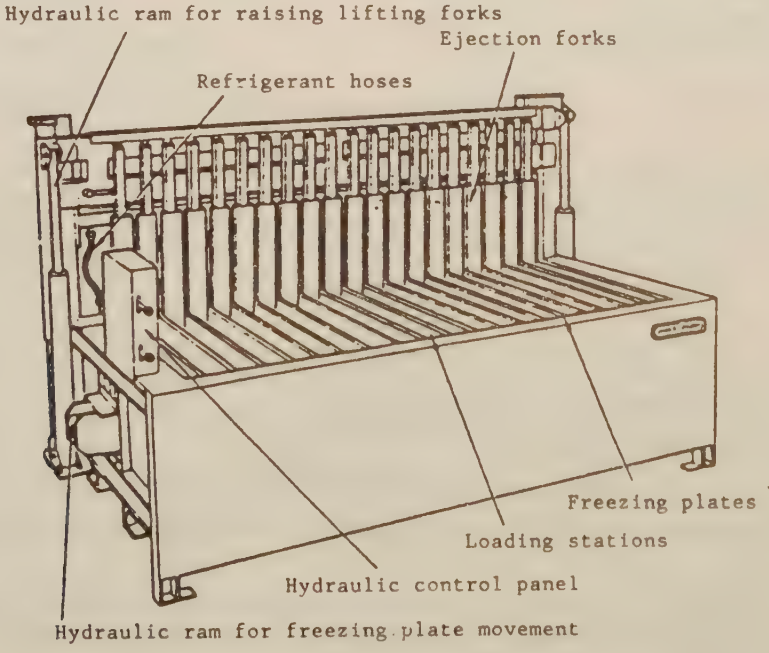


Figure 37 Twenty-station vertical plate freezer with top unloading arrangement

The product is loaded into spaces formed by refrigerated plates which form the stations of a vertical plate freezer unit. The plates are hydraulically closed thereby slightly compacting the product to a preset block thickness and also improving the contact between the fish and the plate surfaces.

After freezing, the cold refrigerant is turned off and a hot refrigerant supply is circulated through the plates to defrost them and break the bond between the plates and the product. This defrost procedure only takes a few minutes and, when complete, the hydraulic system is operated to open the plates and raise the blocks to the top of the freezer ready for removal.

Since the product is frozen into a symmetrical block, it is ideally suited for palletizing to give good utilization of cold storage space. The product can be frozen unwrapped and stored without packaging or frozen in paper or plastic bags which are inserted between the plates before loading the fish. Unwrapped products may, however, be glazed or inserted into cartons after freezing.

3.2.4.2 Freezer size: The size of a VPF unit depends on the plate size, plate spacing and the number of stations.

A plate widely used has dimensions of 1 120 x 558 mm which produces full-sized blocks measuring 1 060 x 520 mm. Other plate sizes available from the same manufacturer give block dimensions of 1 180 x 490 mm and 800 x 806 mm. Other standard sizes may, however, be available from other manufacturers. The provision of a non-standard plate size will be expensive since this may require a special die to extrude the plate sections.

The standard block thicknesses produced in VPF are 50 mm, 75 mm and 100 mm, and by means of special adaptors it is possible to have more than one standard spacing in the same unit.

Any number of stations can be supplied up to a limit of about 30, but manufacturers will normally only supply five or six standard sizes. Special requirements, such as small units for freezing trials or laboratory use, can, however, be made on request.

When selecting the number of stations per freezer unit, account should be taken of the likely pattern of fish supplies. Unit sizes should be selected so that they are likely to be completely filled during each cycle, thus avoiding the possibility of freezing partial loads or having freezers waiting for further supplies to complete a load.

Overall dimensions and weights for a full standard range is given in Table 33.

Table 33

Vertical plate freezers
Dimensions and shipping data (uncrated)

Block thickness (mm)	No. of stations	Dimensions width x depth x height (mm)	Nominal weight
100	12	2 230 x 1 600 x 1 885	1 600
	16	2 735 x 1 600 x 1 885	1 900
	20	3 280 x 1 600 x 1 885	2 200
75	16	2 301 x 1 600 x 1 885	1 800
	20	2 733 x 1 600 x 1 885	2 100
	25	3 240 x 1 600 x 1 885	2 300
50	20	2 230 x 1 600 x 1 885	2 000
	25	2 734 x 1 600 x 1 885	2 200
	30	3 032 x 1 600 x 1 885	2 400

Note: Freezers have standard plates measuring 1 120 mm x 558 mm

3.2.4.3 Refrigeration system: To ensure a good circulation of refrigerant, and hence uniform freezing in all stations, vertical plate freezers use pump circulation of refrigerant. Both primary

and secondary refrigerants are used and all the refrigerants listed in Table 12 are suitable. For safety reasons, ammonia, however, may not be used at sea in some countries.

Refrigerant pump circulation rates are the same as those given in Table 32 for HPF.

Defrosting is an important operation and this is done at the end of each freeze to enable the block to be quickly removed from the freezer. Defrosted plates are also necessary for reloading the freezer. Loading fish between frosted plates results in the fish adhering to the plate surfaces to give low density blocks and the poor contact results in longer freezing times.

With a primary refrigeration system a hot gas defrost can only be achieved if two or more freezer units are operated, and they are defrosted in sequence.

3.2.4.4 Freezing times and freezing capacity: The density of the block after loading is an important factor which affects the capacity of a freezer unit. This will vary depending on the product, and considerable variations can also exist for any given product. Fish size, fish freshness and whether they are still in rigor mortis are all factors which determine how the fish pack between the plates, and thereby determine the final block density.

Variations in block density affect the load that can be contained in the freezer, but this also has an influence on the freezing time since block density relates to the contact made between the product and the plate, and hence freezing time.

Knowledge of the product and hence the block density likely to be achieved is therefore important in the calculation of freezer capacity. There is no accurate method of determining this density other than from past experience or by tests, but in order to give some guidance and show how block weights can vary, some typical figures are given in Table 34.

Table 34

Vertical plate freezers - block weights
(blocks - 1 120 mm x 558 mm x 100 mm)

Product	Block weight (kg)
Whole cod (head on)	46
Whole cod (head off)	49
Herring/sprats	53
Fish fillets	57

As in other cases, accurate freezing times can only be obtained by measurement under closely specified conditions and even when known times appear to relate to the product under consideration, a variation in only one of the conditions can make a significant difference.

The times listed in Table 35 should therefore only be used as a guide during the early stages of planning or for comparison with figures obtained from other sources. The figures relate to good operating conditions and they therefore may not always be obtainable in commercial practice.

Table 35

Approximate freezing times for vertical plate freezers

System: pump circulation Evaporation temperature: -34°C

Product	Product thickness and freezing times			
	50 mm	62 mm	75 mm	100 mm
Fish fillets	60 min	75 min	105 min	165 min
Whole fish	75 min	90 min	120 min	180 min
Herrings/sprat	60 min	75 min	110 min	170 min
Shrimps in cartons	90 min	135 min	160 min	230 min

3.2.4.5 Example calculation: A customer requires 30 t of fish fillets to be frozen, over a working day of 24 h, as 50-mm thick blocks. The initial fish temperature is 10°C and the final temperature after freezing is assumed to be an average temperature of -18°C. The refrigeration plant is to operate with an ammonia pump circulation system.

Freezer requirement:

Freezing time	1 h
Weight of block	27.3 kg
Number of cycles/day	$\frac{24 \text{ h}}{1 \text{ h} + 20 \text{ min}}$
	corresponding to 18 cycles
Weight to be frozen each cycle	$\frac{30\,000 \text{ kg}}{18 \text{ cycles}}$
	corresponding to 1 666 kg
Number of stations required	$\frac{1\,666 \text{ kg/cycle}}{27.3 \text{ kg/station}}$
	corresponding to 62 stations

Two 30-station freezers may therefore be selected to give a slightly reduced capacity of 3 x 20-station units or three units with 12, 20 and 30 stations, respectively, may be more appropriate to match the likely pattern of fish supplies.

Refrigeration capacity:

Heat to be removed (Table 79)	75 kcal/kg
Freezing time	1 h
Load/cycle	1 666 kg
Refrigeration requirement	$\frac{1\,666 \text{ kg} \times 75 \text{ kcal/kg}}{1 \text{ h}}$
	corresponding to 124 950 kcal/h

The figure is derived by taking account of the product load only. In order to allow for the higher refrigeration requirement at the start of freezing, and other refrigeration requirements such as cooling the freezer plates, insulation heat gains and pumping energy transmitted to the system, additional accurate calculations can be made or an arbitrary factor of 30% added to the above value.

Total refrigeration duty required	124 950 x 1.3
	corresponding to 162 435 kcal/h

Table 36

Cost of vertical plate freezers (freezer only)

Description	No. of stations	Plate size (mm)	Cost (US$)
All standard block thickness	12	1 220 x 558	28 500
All standard block thickness	30	1 220 x 558	32 250

3.2.5 Direct contact

The three refrigerants most commonly used in direct contact with the product are nitrogen, carbon dioxide and liquid freon freezant, and information on their properties and other data is given in 3.1.3.

The main advantage in using these refrigerants is that high rates of heat transfer can be achieved and they are therefore all used in freezers intended for a continuous mode of operation.

Another advantage compared with air blast freezing is that there is a reduced weight loss by evaporation and this is often taken into account in costing when comparing with air blast. However, many of the costings are not based on measured weight losses under comparable conditions and care should be taken to ensure that the conditions are relevant to the application under consideration.

3.2.5.1 Nitrogen (N_2): A nitrogen freezer is a total loss system with the nitrogen gas being vented to atmosphere after use. In some situations, natural ventilation may be sufficient, but in more confined spaces forced ventilation may be necessary to maintain the correct oxygen level in the factory air.

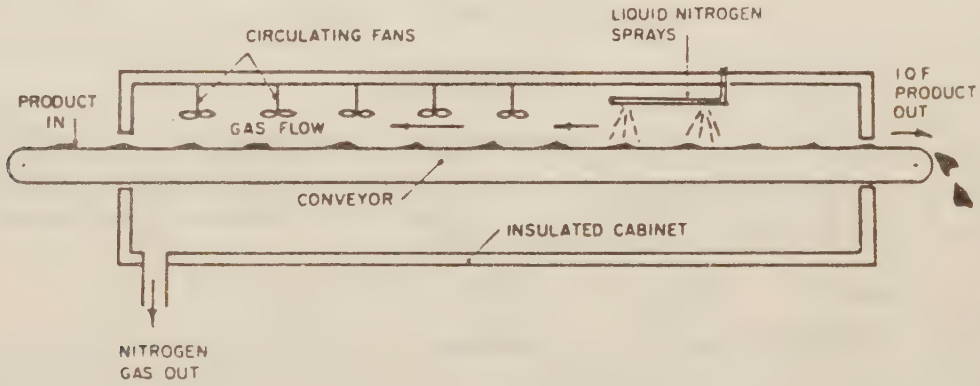


Figure 38 Liquid nitrogen freezer

Freezing can use from one to three times the frozen products weight of nitrogen with lower consumption rates where there is a strict control of the operation and a high freezer utilization value.

The cost of nitrogen freezing has been reported with wide variations depending on the criteria set down for the costing calculations. Care should therefore be taken that when a comparison is made, the conditions are related to the particular application. Calculations made under likely UK conditions show that the total cost of nitrogen freezing is about three times higher than the cost for continuous air-blast freezing and this relationship is even less favourable for nitrogen when compared with bulk air-blast freezing.

The budget costs for a range of nitrogen freezers are given in Figure 39.

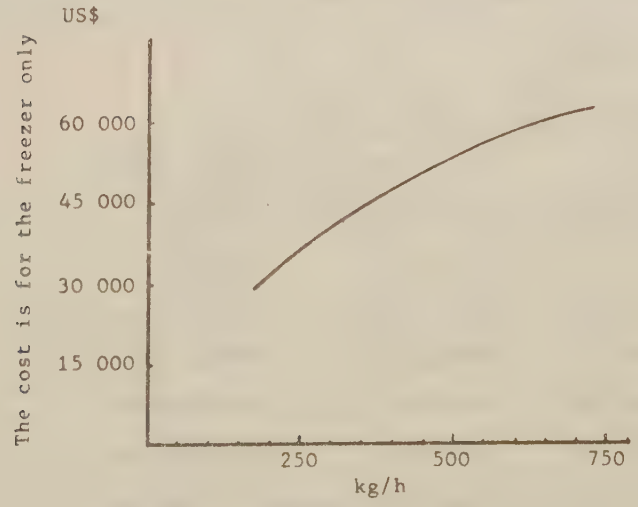


Figure 39 Cost of liquid nitrogen continuous freezers (excluding storage tank)

Nitrogen freezers are more compact than any other type of continuous freezer, but account should also be taken of the space requirement for the on-site storage tank and the need for access for refilling.

Together with freezing costs, continuity of supplies of refrigerant is the major consideration when contemplating the use of nitrogen freezers. In many cases, unavailability of supplies will prohibit their use, but even when there is a suitable supply, other elements of delivery, such as access roads and their condition throughout the year, should be given consideration.

Nitrogen is usually a by-product from other processes, therefore, depending on other likely local uses, the nitrogen may be available at a low competitive price.

3.2.5.2 Carbon dioxide (CO_2): Carbon dioxide is also a total loss refrigerant and it is essential in this case that the gas is ventilated outside the building, since at concentrations of 2% in the working area it will become unpleasant, and at over 10% dangerous.

Carbon dioxide is supplied as a pressurized liquid, but when this is metered into the freezer, it converts to a mixture of solid and gas. Good heat transfer from the product depends on contact with this solid fraction, therefore, if distribution is poor, freezing times will be variable.

Like nitrogen freezing, the cost of carbon dioxide freezing depends on the source of supply since, again, it is also likely to be a by-product. Carbon dioxide freezing will be slightly cheaper than nitrogen freezing, with total costs approximately two-and-a-half times that of continuous air-blast freezing.

Continuity of supplies will also be a major consideration, and additional space for storage of the refrigerants on site will again be a factor to be taken into account.

3.2.5.3 Liquid freon freezant (LFF): Unlike nitrogen and carbon dioxide, most of the refrigerant is recondensed and used again, thus costs are a good deal less at about one-and-a-half times the total cost of air-blast freezing.

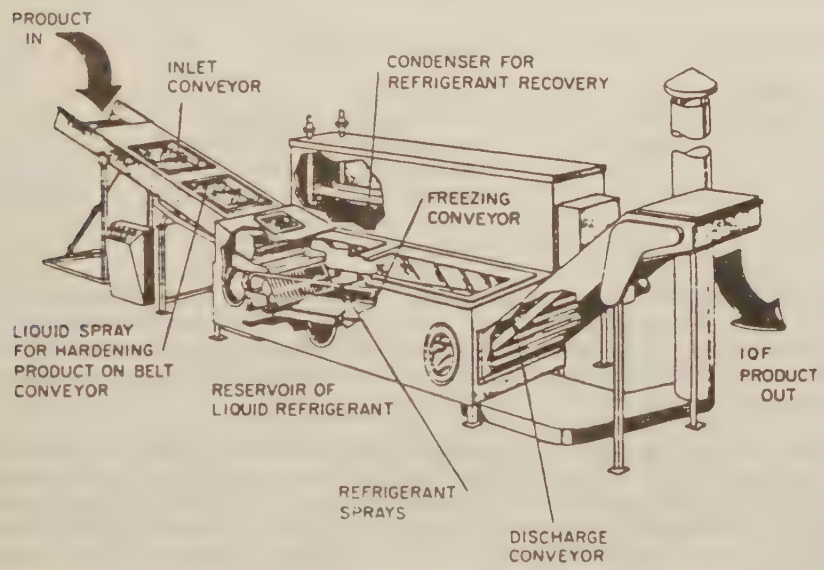


Figure 40 Liquid-freezant freezer

This refrigerant, however, may not be approved for use in direct contact with food locally, or not allowed for freezing foods imported into some countries, therefore, it may not be an option which can be considered.

Although LFF incorporates some of the advantages that are associated with other liquified gases, the need to have a mechanical refrigeration system for recondensing the refrigerant does not make it independent of a suitable electrical supply or other motive force as is the case with the others.

3.3 Packaging and Glazing

3.3.1 Packaging

3.3.1.1 Need (Table 37)

(i) General: The main functions of packaging are envelopment, protection and identification. Packaging of frozen fish will reduce the main spoilage mechanisms, i.e., dehydration and oxidative rancidity. Packaging will also provide protection against mechanical damage and contamination, and it will also allow the product to be identified both for storage management and for customer information at the point of sale.

(ii) Package descriptions:

Carton - Any box of card or plastic which fully encloses the packaged material. "Carton" tends to be used for smaller boxes and "master carton" for large boxes used to hold collations of smaller packs.

Vacuum packing - packs which are evacuated then sealed so that virtually no air is inside the pack.

Boil-in-the-bag - Generally vacuum packed; the product is cooked by boiling. The packaging film used must be effective under boiling conditions.

Stretch wrap - The product is packaged in a thin elastic film which is stretched tight. Often a "cling" film is used which has good, dry adhesion to itself and to other smooth dry surfaces.

Shrinkwrap - The product is packaged in a film, generally medium to thick, which shrinks in one or both directions when heated.

Overwrap - The product is packaged in a film which is wrapped loosely and sealed.

(iii) Abbreviations: The following abbreviations are sometimes used for packaging film materials.

Abbreviation	Trade/generic name	Chemical name
PA	"Nylon"	Polyacetal
PE	"Polythene"	Polyethylene
PVdC	"Saran" "Cryovac"	Polyvinylidene chloride
PVC	-	Polyvinyl chloride
PP	-	Polypropylene
OPP	-	Oriented polypropylene
PET	-	Polyester

3.3.1.2 Frozen packs: There are many different packing materials used for fish, and it would be unrealistic to try to list them all. Only the more widely used materials are therefore mentioned, and the tables give the more salient properties only. Quantities required should be determined after discussion with the makers of packaging machinery since wastage can be as high as 10%, particularly with preprinted material and high-speed machinery.

The two main properties, which must be considered in packaging material for fish, are water vapour permeability which determines the extent of dehydration and gas permeability which determines the extent of oxidative rancidity. As can be seen from the tables, there is no ideal single material and, generally, films are laminated to optimize the properties of two or more. Thicker films form better barriers but cost more, therefore, a compromise has often to be made. Thicker films, however, are essential for rigid-formed packs.

The basic films have a 2-1 cost spread, but the final cost will depend on lamination, printing and processing, and this will result in an even wider price range, depending on the specification.

Packaging should be carried out as soon as possible after freezing, but if delay is unavoidable, the frozen product should be held in closed, lidded containers in a cold store.

The choice of packaging film will, to some extent, depend on availability. Local suppliers should be contacted for appropriate costs. It must not be forgotten that packing materials intended for other goods may not be suitable for frozen fish.

Table 37

Packaging methods and applications

Method	Details	Process	Function/use
Coated paper bags	Polythene-lined sacks	Hand	Water-filled blocks 20-50 kg, whole (fatty) fish
"	Metallized laminate	Hand/M/c	Bulk pack - fish sticks, etc., (2.5 kg), reclose by folding
Plastic film bags	Polythene - laminates (preferable)(generally transparent - sometimes overprinted - can be metallized or opaque)	Hand	Whole fish blocks 20-50 kg. Can be unstable unless friction film used.
		Hand	Cover for pallet of blocks or boxes
"	Heat-sealed	Hand/M/c	Bulk packs (up to 2 kg) of IQF products
		Usually M/c	Outer seal on small cartons
"	Film pulled tight by vacuum	M/c	IQF fillets, etc., good appearance
"	Vacuum-packed and suitable for boil-in-bag cooking	M/c	IQF-smoked fish. Fish-in-sauce and prepared dishes
Shrink/stretch film	Shrink applied as sheet or tube. Shrunk by heating	Hand/M/c	(a) Used to stabilize and cover pallets (b) IQF portions, enrobed products with tray (where enrobing might damage vacuum pack film)
	Stretch elastic film. Both can be heat-sealed	Hand/M/c	as (b) above
Cartons	Waxed or laminated board	Hand	For fillet blocks
		Hand/M/c	For IQF products
		Hand/M/c	Outer cover for products in film bags
	Corrugated paper	Hand/M/c	Master cartons for smaller packages
Trays	Plastic	Foil Plain Foam Ovenable	Used with shrink or stretch film for IQF products
"	Fibre		Used with inserted or heat-sealed lids for prepared dishes
Boxes	Polystyrene foam		Used as an outer cover for packs of whole shellfish, e.g., Nephrops
Pallets	(Not strictly packaging, but used as the basis for collection of blocks and cartons)		

Table 38

Typical laminates compared with PE and PA

Material	Thickness (mm)	Permeability		Seal Temperature (°C)	Form depth Maximum (mm)
		Water Vapour	O_2		
PE	0.10	1	100	130-150	
PA	0.10	20	1	180-260	
PE	0.20	0.5	50	130-150	
PA/PE 30/70	0.10	1.8	5	120-200	
PE/PVdC/PE	0.10	0.4	0.1	130-200	
PA/PVdC/PE	0.10	1.4	0.3	120-200	40
PA/PVdC/PE	0.25	0.8	0.1	120-200	150
Alum foil/PE 16/84	0.034	∿0	∿0	120-200	

Note: (1) As can be seen from the Table, water vapour permeability properties should be compared with the excellent qualities of PE, and oxygen permeability with the good qualities of PA

(2) For both permeability figures low values are the better

3.3.1.3 Equipment: Packaging equipment may vary between a simple hand-operated tool and a complicated machine, therefore, a range of methods are listed in Table 40 to suit all eventualities for a variety of packaging operations.

The type of machinery selected will depend on many factors, some of which will be greatly influenced by local conditions, therefore, independent advice should be taken for each application.

3.3.1.4 Labelling: It is possible for all the label information to be incorporated at the pack manufacture stage. This is appropriate where large runs of a product in a fixed weight pack are used and where no date or serial markings are required. Secondary labelling or marking is used to apply extra information to a pre-printed bag or carton. For instance, the contents of a master carton or the date mark, or weight on a smaller package, could be marked by a separate printer. Labelling machines are availabe and, of course, labels and markings can be hand-applied. Table 40 gives examples of available equipment. The decision as to when labelling and marking is to be done depends on the type of equipment and materials being used, and many labelling machines are designed to be incorporated in packaging machinery or conveyors.

Prices of label dispensers vary from US$ 750 for a simple machine up to US$ 7 500 for machines with overprinting and programmable controls. Overprinters vary from US$ 300 upwards. A form of coding can be incorporated into bag-sealing apparatus at low cost.

3.3.1.5 Space: The space requirements for packaging will depend on the methods used. Manufacturers should be consulted for information on machinery sizes. Plant layout should be determined, using flow charts and space allowed for conveyors and access.

At this stage of the operation it may also be necessary to weigh or check-weigh packages and to pass packages through a metal detector. Space must be allowed for this.

3.3.2 Glazing

Glazing is the application of a layer of ice to the surface of a frozen product by spraying on water or by dipping the product in water, and it is a widely used means of protecting frozen fish products from the effects of dehydration, oxidation and other changes during cold storage.

Table 39

Properties of basic materials

Material	Uses	Type thickness (mm)	Strength (higher = better)		Permeability (lower = better)			Process			High temperature
			Tensile	Tear	WV	Gas (Oxygen)	Grease/Oil	Heat seal (°C)	Stretch	Shrink	
Waxed or polycoated White bleached board or chip board	Cartons	0.30 to 0.70	-	-			Impervious	-	-	-	-
Cellophane	Bags etc	varies usually laminated to give 0.03 to 0.30	9	0.02	0.4	0.8	Impervious	90-180	No	No	No
Polythene (PE) low density	"		1	1	1.0	100	Fair	120-180		Some	No
Polythene medium density	"		2	0.5	0.4	60	Good	130-150		Some	No
Polythene high density	"		3	0.15	0.3	15	Good	135-150		Some	Yes
Nylon (PA)	"		7	0.20	20	1	Impervious	180-260		No	Yes
Polypropylene (PP) (oriented)	"		25	0.04	0.3	40	Good	No		Some	Yes
PVC	"		2 upwards	Varies	> 3.3	2 to 500	Good	120-180	Yes	Some	No
PVdC (Saran)	"		8	0.1	0.1	0.2	Good	120-150	Yes	Some	No
Polyester (PET)	"		25	0.13	1.1	2	Good	No		Some	Yes
Aluminium Foil	"	0.009 to 0.012	-	-	0.1	3	Good	No	-	-	Yes

NOTES: 1 Tensile, tear and water vapour (WV) qualities are relative to PE which has unit value

2 Gas permeability is related to PA which has unit value

Table 40

Packaging machinery

Method	Manpower	Throughput	Typical space (M/C only) length x depth x height	Energy	Cost $	Remarks
Heat sealing	Manual (1)	–	Bench	70–300 W	75–300	Static. Intermittent use
	Manual (1)	–	Bench	500 W	900	Rotary Band. 5-h day
	Semi Auto(1)	Up to 200 mm/s	0.85 x 0.70 x 1.77 m	900 W	2 000	Rotary Band. 12-h day
	Semi Auto(1)	150–200 mm/s	1.25 x 0.90 x 1.68 m	1 400 W	7 000 to 10 000 Higher price for optional coding and bag trimming	Rotary Band. Continuous
	Semi Auto(1)	–	0.89 x 0.69 x 1.45 m	500 W	1 900	'L' sealer for film
Vacuum packing Bag fed	Manual (1)	15–20 s cycle + filling time Chamber 370 x 380 x 140 mm	0.46 x 0.56 x 0.43 m Table model	550 W	2 700 to 3 200	Single chamber machines
	Manual (1–2)	20–24 s cycle + filling time Chamber 1 000 x 700 x 200 mm	1.18 x 1.17 x 1.05 m	4.0 kW		
	Semi Auto(1–2)	20–24 s cycle Each chamber 440 x 540 x 160 mm	1.27 x 0.95 x 0.98 m	1.5 kW		Twin chamber machines
	Semi Auto(1–2)	20–24 s cycle Each chamber 610 x 815 x 160 mm	1.62 x 1.24 x 1.10 m	4.0 kW		
	Automatic(1)	– Chamber 825 x 745 x 180 mm	1.79 x 1.09 x 1.45 m	1.5 kW		Belt loaded machines
	Automatic(1)	25–30 s cycle Chamber 950 x 1 110 x 200 mm	2.31 x 1.37 x 1.62 m	0.9 kW		
Vacuum packing Reel fed	Automatic(2–6) (hand loading)	4 s cycle Varying chamber areas 285 x 320 to 620 x 800 mm	4 x 0.65 x 1.63 to 6.54 x 0.82 x 1.70 m	6 to 7.5 kW + compressed air and water	30 000 to 66 000	
Tray sealed lid	Semi Auto(1)	2–4 packs/min	0.77 x 0.45 x 0.45 m	1 kW	Up to 10 000	
Tray stretch wrap	Semi Auto(1 + tray filling)	Up to 35 packs/min	2.98 x 1.02 x 1.46 m	1.5 kW	8 000 upwards	
" "	Automatic(1 + tray filling)	50–60 packs/min Tray min 120 x 90 x 10 mm Max. 270 x 230 x 130 mm	(2.77 to 7.37) x 1.36 x 1.31m	2 kW	32 000 to 45 000	
Tray shrink wrap	Automatic(1)+ tray filling)	Up to 60 packs/min	(4 to 8) x 1.5 x 1.8 m	12 kW upwards	30 000 upwards	
Tray overwrap	Automatic(1 + tray filling)	Max. 120 packs/min Tray min. 80 x 30 x 1 mm max. 700 x 220 x 100 mm	3.25 x 0.95 x 1.62 m	2.5 kW	18 to 45 000	

Table 40 (continued)

Method	Manpower	Throughput	Typical space (M/C only) length x depth x height	Energy	Cost $	Remarks
Foil tray lidder	Automatic(1 + tray filling)	Max. 120 packs/min Tray min. 140 x 113 mm min. 140 mm dia max. 314 x 276 mm max. 276 mm dia	5.65 x 0.76 x 1.83 m	2.5 kW	37 500 upwards depending on options	
Carton sealing	Semi Auto(1)	Up to 60 packs/min (depends on operator) Tray min. 100 x 44 x 22 mm max. 355 x 266 x 100 mm	(1.83 to 2.97) x 1.14 x 1.10	3.5 kW	9 000 to 13 500	Operator forms cartons
Carton forming	Automatic (+ product loading)	60 to 120 packs/min Tray min. 100 x 44 x 22 mm max. 355 x 266 x 100 mm	(3.60 to 4.40) x 1.14 to 2.09 x 1.60 m + infeed conveyors	5 kW	30 to 45 000	
	Semi Auto(1) (operator loads product)	Up to 100 packs/min Tray min. 100 x 44 x 22 mm max. 355 x 266 x 100 mm	4.34 x 1.14 x 1.60 m + infeed conveyor	5 kW	from 27 000	
Master carton taping	Manual (1)	Varies	Bench	–	12-20	Pistol-type machine
	Semi Auto(1)	Operates at up to 18 m/min Box 75 x 114 mm sq up to any length x 508 mm sq	0.9 x 0.7 x 1.3 m	0.1	2 500 to 3 000	Must be adjusted for different box sizes
	Automatic(1)	Operates at up to 18 m/min Box 150 x 114 mm sq up to any length x 508 mm sq	1.07 x 1.09 x 1.42 to 2.24 x 1.04 x 2.06 m	Up to 0.8 + air in some cases	6 000 to 30 000	
Master carton strapping – polypropylene straps	Manual (1)	Varies	Bench	Hand operated also air/electric at higher prices	150 to 300	Strap fed by hand
	Semi Auto(1)	17/min, size limited by table	0.90 x 0.56 x 0.78 m	0.8	1 800 to 3 000	Box on table
	Automatic	17/min, size limited by arch 500 mm sq up to 1,000 mm sq	0.6 x 1.4 x 1.6 to 0.6 x 1.6 x 1.6 m	1.2 to 1.6	6 000 to 9 000	Box passes through arch
Master carton string tying	Semi Auto(1)	40/min, size limited by arm swing	0.9 x 0.9 x 1.5 m	0.55	3 500	
Heat shrinking	Manual (1)	–	Bench	Gas	600	Hand held shrink gun
Heat shrinking	Automatic	Varies	Usually incorporated in machines	Varies	1 200 upwards	
Stretch wrap	Manual (1 + pallet truck operator)	Varies	Bench	–	50	Dispenser for 400-mm wide film
" "	Semi Auto 1 + pallet truck operator	About 30 pallets/h	2.80 x 1.83 x 2.44 m	2.5 kW	7 600 to 14 700	

Note: Data for typical machines. Local prices and availability may vary

An ice glaze is, in effect, a tight fitting wrapper, but unlike other wrappers it is not permanent since the ice is lost by sublimation in the cold store. Periodic inspection and reglazing, as necessary, is therefore required, particularly if no other wrapper is used.

Water used for glazing must be of a potable quality, and when a dipping method is used the water should be periodically changed.

On applying a glaze, it is necessary to ensure that all the surfaces are covered, and in circumstances where the amount of glaze added is important, the glazing operation should be done under strictly controlled conditions.

It is not practical to measure the thickness of an applied glaze, and usually glaze will not be of a uniform thickness over all surfaces. Glaze is therefore defined as a percentage of the product weight and this will vary considerably with the size and shape of the product, even when the glaze thickness is the same.

For instance, a large 45-kg block of cod, quickly dipped in chilled water, will have a glaze of about 1.5%, which corresponds to a mean thickness of 0.5 mm, whereas a single fillet dipped in a similar manner will have a glaze of about 8% with a mean thickness of 0.25 mm.

Under these conditions, the larger surface area per unit weight of the smaller fillet results in a higher percentage glaze, but the difficulty of handling the larger block quickly in and out of the water results in a longer immersion time and a thicker glaze.

When glaze is applied in an uncontrolled manner, large variations can result and values between 2% and 20% by weight have been measured in an IQF fillet-glazing operation. Even when the process is controlled, there are difficulties in keeping the glaze within specified limits, and this may result in complications when glaze has to be accounted for in the selling weight.

The factors which influence the amount of glaze taken up are as follows:

- Glazing time
- Fish temperature
- Water temperature
- Weight grade (product size)
- Product shape

It is possible to control some of these factors, such as glazing time and fish temperatures, particularly if a continuous glazing operation is used immediately after freezing. In some climates, seasonal changes in the temperature of the domestic water supply can significantly change the weight of glaze added, but with a continuous system, glazing time can be varied to compensate for this. However, even when glazing conditions are strictly controlled, glaze variations will exist.

With larger products, such as the 45-kg block mentioned above, differences may be insignificant since the total glaze is only a small percentage of the product weight. With 100-g fillets, strict control of a continuous spray-glazing process resulted in a mean glaze of 6.2% with a statistical probability of 5% of the fillets having a glaze outwith the range of 5.1-7.3%. This glazing operation also showed that with glazing times which result in less than 4% glaze, the product was not completely covered and with a glaze and above 8% there was some partial thawing at the edge of the fillets. Therefore, even with good glazing practice, minimum and maximum glazing limits will apply, and possible variations should be confined within this range.

Glazing also adds heat to the product and excessive glazing will mean a considerable additional product heat load when it is placed in cold storage.

The heat added and subsequent equilibrium temperatures for normal and excessive glazing are given in Table 41.

Standard designs of continuous glazing machines are not readily available, and many are therefore built to the processors specification only. Basically, a machine consists of an enclosed variable-speed open mesh conveyor belt with water sprays above and below to cover all surfaces of the product. Manufacturing costs should be between US$ 3 000 and US$ 6 000, and the following specification is typical for an in-line unit:

- Capacity - 2 000 kg/h of IQF fillets
- Dimensions - 2 m x 1 m x 1 m
- Power requirement - less than 2 kW
- Water consumption - 300 litres/h
- Cost - approximately US$ 5 000

Table 41

Heat added and equilibrium temperature after glazing
(initial fish equilibrium temperature -30°C)

Glaze (%)	Equilibrium temperature (°C)	Heat added (kcal/kg fish)
1	-28	1.0
2	-26	2.0
4	-23	3.9
6	-20	5.8
10	-14.7	9.6
15	- 9.6	14.8
20	- 6.3	19.6

4. STORAGE AND EQUIPMENT

4.1 Storage Conditions

4.1.1 Recommended conditions

Recommendations and codes of practices which relate to the storage of frozen fish products are not always applied, and in many cases they are a compromise or merely state the minimum requirements. Individual countries, or even companies, may have their own standards, therefore, potential customers should be consulted on their requirements before decisions are made on cold storage conditions.

One of the reasons for the differences between one source of information and another is that different criteria are often used to define maximum storage time. In some cases this may be based on a good quality product, whereas in others it may be sufficient that the product is still edible. Maximum storage times must therefore be clarified by also stating the standards applied.

In most recommendations, storage times are given for different temperatures and this may imply that the design temperature of the store need only be sufficient for the storage times contemplated. Cold stores, however, are seldom used for one product only and often the total storage time is made up of stopovers in a series of stores along the marketing distribution chain. Cold stores should therefore be built for the most demanding conditions rather than those immediately contemplated. For instance, it may be realistic to build a store for fatty fish for a total storage time of one year and, thus, ensure good storage conditions for all fish products from one season to another.

Table 42 contains UK recommendations for a temperature of -30°C. The Table gives the period within which the product is for all purposes, as good as fresh and the figures should be regarded as the highest obtainable under ideal conditions.

Another set of recommendations, which are now under review, have been issued by the International Institute of Refrigeration in the second edition of their book "Recommendations for the processing and handling of frozen foods", and these are listed in Table 43. In this case, the times are for practical storage life which is defined as the time the product remains suitable for consumption or for the process intended.

A number of codes of practice for fish and fishery products, elaborated by the Codex Alimentarius Commission, Joint FAO/WHO Food Standard Programme, also make recommendations for storage conditions and these are listed elsewhere in this document.

In addition to temperature, humidity is also important, and for the storage of frozen fish products relative humidity in the store should be maintained at as high a level as possible to avoid excessive dehydration of unwrapped produce. The relative humidity within the store relates to the difference in temperature between the cooler surfaces and the control temperature of the air. Large cooler surface areas require smaller temperature differences to transfer the heat, and this will result in a higher relative humidity. Conversely, a small cooler operating with a large temperature difference will result in a low relative humidity. A compromise has therefore to be made between

Table 42

Cold storage lives at -30°C

Item	Storage life months
White fish, gutted	8
Smoked white fish	7
Herring and mackerel, gutted or ungutted	6
Kippers	4½
Shellfish	
raw whole or shelled Nephrops and cooked shucked mussels	8
raw shrimp, raw whole oysters and scallop meats	6
cooked shrimp, cooked whole crab and lobster	6
extracted crab meat	4

Table 43

Practical storage lives of fish products

Product	Storage life in months		
	-18°C	-25°C	-30°C
Fatty fish	4	8	12
Lean fish	8	18	24
Flatfish	10	24	> 24
Shrimp	6	12	12

cost, size of the cooler and storage conditions, and a temperature difference of 5°C is a normal design figure. This will give a relative humidity of about 85-90%, but in special designs, such as jacketed cold stores, relative humidities of 98% and higher are possible.

Any situation that results in a rise in the store temperature is likely to reduce the relative humidity of the air, therefore, loading warm produce and leaving doors open for long periods should be avoided.

Even when product is frozen down to the intended storage temperature in an adjacent freezer, it is difficult to avoid the product warming up on being transferred to the store. In the cold storage refrigeration load calculations, allowance is made for a product load equivalent to a 10°C temperature rise, and this should be the intended limit for all produce.

4.1.2 Densities and stowage rates

Figures for density and stowage rate of frozen fish products are not meaningful, unless the exact conditions are clearly defined. For instance, cartons of fish fingers stored on pallets in master cartons can have a stowage rate of between 2.4 and 3.1 m^3/t, depending on the weight in the individual carton packages. Clearly, if this difference exists with such a well defined and regular shaped item, there will be little benefit to the designer or cold store operator if only average or typical figures are given or, alternatively, figures are quoted as a range to cover all eventualities. In the following Tables, both detailed and general figures are quoted and these are clearly destinguished so that they are used with the appropriate degree of discretion.

Other than where it is stated, all stowage rates are for pallet loads only and exclude allowances for passageways, etc.

Table 44

Density and stowage rates
Fillets IQF - polystyrene trays with stretch wrap

Wt of pack (kg)	Total wt in master carton (kg)	Dimension of pack (mm)	No of packs in master carton	Dimension of master carton (mm)	Density in master carton (t/m^3)	No of master cartons per pallet	Total wt per pallet (kg)	Stowage rate with pallet (m^3/t)
.284	1.7	188 x 135 x 30	6	305 x 190 x 140	.21	200	340	5.9
.227 to .298	2.3	220 x 130 x 30	10	270 x 235 x 195	.19	119	274	7.4
.255 to .369	2.3	270 x 138 x 18	9	400 x 300 x 100	.19	150	345	5.8
.255 to .369	4.6	270 x 138 x 18	18	400 x 280 x 194	.21	70	322	6.3
.173 to .355	4.6	215 x 130 x 30	18	260 x 220 x 335	.24	68	313	6.4
.184 to .340	7.25	264 x 131 x 25	35	400 x 297 x 260	.23	50	360	5.6

The number of packs in a master carton depends on the catch weight of the pack. The numbers given are the maximum possible

Table 45

Densities and stowage rates
Fish fingers - cartons and bag packs

Wt of pack (kg)	Type of pack	Dimension of pack (mm)	Density in pack (t/m^3)	No of packs in master carton	Dimension of master carton (mm)	Density in master carton (t/m^3)	No of master cartons per pallet	Total wt per pallet (kg)	Stowage rate with pallet (m^3/t)
.150	Carton	110 x 100 x 30	.45	48	375 x 230 x 210	.40	91	655	3.1
.255	"	180 x 100 x 30	.47	48	390 x 210 x 365	.41	60	734	2.7
.255	"	182 x 100 x 32	.44	24	380 x 305 x 130	.41	110	673	3.0
.580	"	200 x 100 x 55	.53	10	290 x 215 x 210	.44	133	771	2.6
2.89	"	280 x 196 x 112	.47	-	280 x 196 x 112	.47	286	827	2.4
.850	Bag pack	115 x 95 x 135	.58	12	300 x 245 x 300	.46	85	867	2.3
1.45	"	170 x 100 x 155	.55	6	355 x 300 x 165	.50	99	861	2.3

Table 46

Density and stowage rates
Fillets IQF - bulk catering packs

Wt of pack (kg)	Type of pack	Dimension of carton (mm)	Density in carton (t/m^3)	No of cartons per pallet	Total wt per pallet (kg)	Stowage rate with pallet (m^3/t)
2.7	Carton	374 x 235 x 100	.31	195	527	3.8
3.2	"	379 x 238 x 115	.31	169	541	3.7
3.6	"	379 x 238 x 115	.35	169	608	3.3
4.1	"	333 x 250 x 150	.33	140	571	3.5
4.5	"	375 x 284 x 100	.42	150	675	3.0
6.4	"	410 x 270 x 185	.31	78	499	4.0
9.1	"	435 x 278 x 250	.30	54	491	4.1

Table 47

Density and stowage rates
Fish portions

Wt of pack (kg)	Type of pack	Dimension of pack (mm)	Density in pack (t/m^3)	No of packs in master carton	Dimension of master carton (mm)	Density in master carton (t/m^3)	No of master cartons per pallet	Total wt per pallet (kg)	Stowage rate with pallet (m^3/t)
.2	Carton	140 x 140 x 20	.51	48	430 x 300 x 180	.41	72	691	2.9
.6	"	145 x 140 x 40	.74	12	435 x 295 x 115	.49	104	749	2.7
.71	"	190 x 175 x 48	.44	12	360 x 300 x 200	.39	70	596	3.4
.95	"	240 x 137 x 50	.58	8	282 x 218 x 250	.49	108	821	2.5
1.1	"	212 x 115 x 70	.64	12	475 x 225 x 220	.56	60	792	2.5
2.4	"	333 x 245 x 76	.39	-	333 x 245 x 76	.39	252	605	3.3
2.5	"	240 x 180 x 115	.50	6	500 x 185 x 355	.46	48	720	2.8
3.2	"	258 x 208 x 80	.75	6	430 x 280 x 260	.61	45	864	2.3

Table 48

Density of stowage rates
Fillet blocks

Wt of block (kg)	Dimension of block (mm)	Density (t/m^3)	No of Blocks per pallet	Total wt per pallet (kg)	Stowage rate with pallet (m^3/t)
5.7	505 x 263 x 38	1.13	176	1003	1.3
6.1	508 x 295 x 41	1.0	168	1025	1.2
6.4	629 x 264 x 38	1.01	160	1024	1.2
7.5	483 x 252 x 58	1.06	128	975	1.4
8.4	484 x 288 x 56	1.08	120	1008	1.2
12	798 x 249 x 60	1.01	84	1008	1.7[a]/
25	530 x 525 x 102	0.88	40	1000	1.3
29	802 x 533 x 65	1.04	34	986	1.3
50	1060 x 530 x 102	0.88	20	1000	1.3

Notes: (1) Pallet loads kept to nominal 1 t

(2) No pallet convertors used - pallet loads stacked on top of each other

(3) 40-mm pallet overlap allowed on each side

a/ Dimensions not ideal for maximum utilization of standard pallet

Table 49

Density and stowage rates
Fish cakes

Wt of pack (kg)	Type of pack	Dimension of pack (mm)	Density in pack (t/m^3)	No of packs in master carton	Dimension of master carton (mm)	Density in master carton (t/m^3)	No of master cartons per pallet	Total wt per pallet (kg)	Stowage rate with pallet (m^3/t)
.1	Poly sleeve	75 x 150 x 15	.60	72	480 x 240 x 165	.38	90	648	3.1
.5	Poly bag	75 dia x (180 + 80)	.63	12	300 x 235 x 180	.47	128	768	2.6
1.0	Bag pack	137 x 68 x (170 + 80)	.63	8	390 x 310 x 165	.40	90	720	2.8
3.6	Carton	300 x 230 x 123	.42	-	300 x 230 x 123	.42	192	691	2.9

Table 50

Density and stowage rates
Fillets IQF - polybags

Wt of pack (kg)	No of packs in master carton	Dimension of master carton (mm)	Density in master carton (t/m^3)	No of master cartons per pallet	Total wt per pallet (kg)	Stowage rate with pallet (m^3/t)
.700	12					
.800	6	400 x 300 x 135	.30	110	528	3.8
.800	12	400 x 300 x 210	.38	63	605	3.3
.800	12	330 x 292 x 280	.36	55	528	3.8
.800	12	395 x 295 x 290	.28	50	480	4.2
.800	15	423 x 269 x 271	.39	54	648	3.1
.907	10	435 x 278 x 250	.30	54	490	4.1

Table 51

Density and stowage rates
Fish portions in batter

Description of product	Wt of Pack (kg)	Type of Pack	Dimension of pack (mm)	Density in pack (t/m^3)	No of packs in master carton	Dimension of master carton (mm)	Density in master carton (t/m^3)	No of master cartons per pallet	Total wt per pallet (kg)	Stowage rate with pallet (m^3/t)
2 oven cod	.2	carton	182 x 117 x 28	.34	24	350 x 240 x 187	.31	104	499	4.0
2 crispy cod	.2	carton	174 x 118 x 28	.35	24	355 x 245 x 183	.30	104	499	4.0
6 oven cod	.6	carton	185 x 114 x 72	.4	8	300 x 192 x 235	.36	120	576	3.5
6 crispy cod	.6	carton	172 x 116 x 61	.5	8	250 x 185 x 242	.43	144	691	2.9

Table 52

Density and stowage rates
Fish portions in sauce

Description of product	Wt of pack (kg)	Type of pack	Dimension of pack (mm)	Density in pack (t/m^3)	No of packs in master carton	Dimension of master carton (mm)	Density in master carton (t/m^3)	No of master cartons per pallet	Total wt per pallet (kg)	Stowage rate with pallet (m^3/t)
Cod portion in sauce	.15	Satchet in carton	130 x 90 x 22	.64	72	400 x 195 x 297	.47	75	810	2.5
Haddock portion in sauce	.15	"	125 x 90 x 22	.61	72	390 x 190 x 300	.49	75	810	2.5
Cod portion in sauce	.15	"	126 x 90 x 25	.53	72	390 x 190 x 300	.49	75	810	2.5
4 cod portions in sauce	.6	Satchet in carton	183 x 115 x 45	.63	12	300 x 195 x 245	.50	120	864	2.3

Table 53

Density and stowage rates
Nominal values for various frozen products

Product	Density (t/m^3)	Stowage rate (m^3/t)
Frozen whole gutted cod in large blocks - weight of fish within dimensions of the block	.64 (fish very loosely packed in block)	1.6
avg.	.88 (very compact block)	1.1
	.77	1.3
Frozen whole gutted cod in large blocks, including allowance for supporting structure access, etc	.50	2.0
Frozen fillets in large blocks, including allowance for packaging, structure, access, etc	.64 to .80	1.6 to 1.3
Frozen whole gutted cod, stowed as single fish	.40 to .48	2.5 to 2.1
Frozen whole gutted halibut: in wooden boxes	.48 to .56	2.1 to 1.8
stowed loose	.61	1.6
Frozen whole salmon: stowed loose in wooden boxes	.53 to .56	1.9 to 1.8
Frozen shelled shrimps in blocks	.72 to .88	1.4 to 1.1
Frozen shelled shrimp in blocks, including allowance for packing structure, etc.	.59 to .72	1.7 to 1.4
Frozen breaded shrimp in consumer packs in master carton	.40 to .48	2.5 to 2.1

4.1.3 Handling

The method of handling and the degree of mechanization used will depend on both the size of the store and the mode of operation.

Larger stores will inherently require more mechanization since greater quantities of produce have to be moved and stacking heights are higher. Some stores may only be loaded and unloaded infrequently with a minimum of traffic in and out, therefore, there may not be a requirement for a highly mechanized system to move produce quickly. Other stores may be relatively small but with a good deal of traffic and a quick turnover of produce. In these cases, more mechanization may be justified in spite of high costs.

Even when labour is readily available and probably the cheapest method of handling, consideration may have to be given to a degree of mechanization to speed up traffic in and out of the store and thereby avoid long periods when the door is left open. Some simple mechanical aids may also be required to reduce physical effort.

A compromise may also have to be made between strong but more expensive packaging which will allow higher stacking in the store and a palletized or racked system which involves higher capital costs.

Another penalty often incurred with quick handling methods is that more storage space is required for manoeuvring handling equipment, and this means higher cold storage capital and operating costs.

The type of product will influence the method of storing and handling.

Large, regular shaped blocks may be stacked on pallets with one directly on top of the other. If the packages are fragile, supporting structures will be required and, whatever the product, unframed or unsupported pallets should be limited to only two pallets high in the interest of safety. Pallet loads may be placed on the shelves of a fixed racking system, or the pallets may be fitted with a converter which is a sectional steel frame surrounding the load (Figure 41). Mesh sides can be incorporated in the converter frame and non-regular shapes, such as single fish or broken blocks, can then be stored loosely within a regular stacking system.

Loading in pallets also allows full or part loads to be kept separate and identified so that they can be removed with the minimum amount of re-arrangement within the store.

A maximum stack height of six pallets is common in large stores with a roof clearance height of about 10.5 m.

A number of mechanical aids are used for stacking pallets, and when it is considered that a pallet load has a nominal weight of about 1 t, these devices are essential even in the smallest stores.

The minimum requirement would be a hand-operated pallet truck (Figure 42), and for a quick movement of produce this may be mechanized (Figure 43). Better utilization of floor space is achieved with reach trucks (Figure 44). Floor utilization can be improved even further if narrow aisle racking is used with a turret truck (Figure 45), which is, however, more expensive and less versatile. Other mechanical aids are the hand-operated fork-lift stacker (Figure 46), and for reavier duty the fork-lift truck (Figure 47).

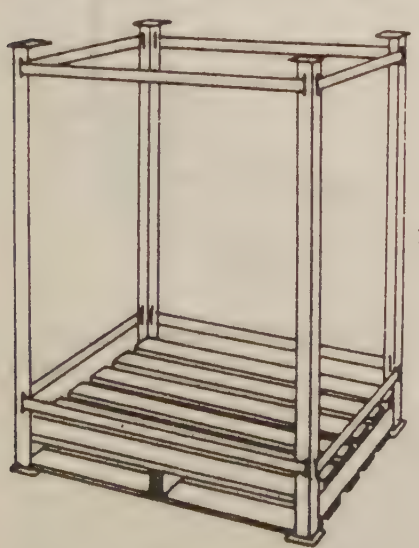


Figure 41 Pallet with converter frame

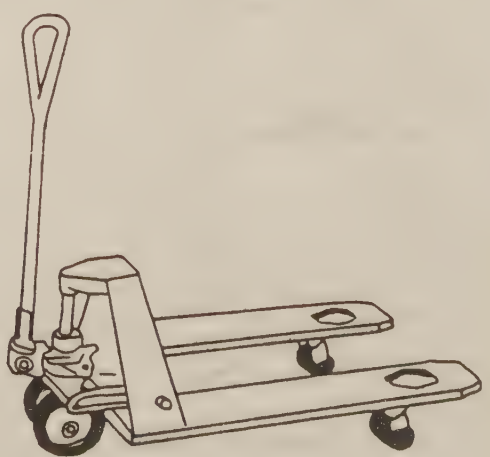


Figure 42 Hand-pallet truck

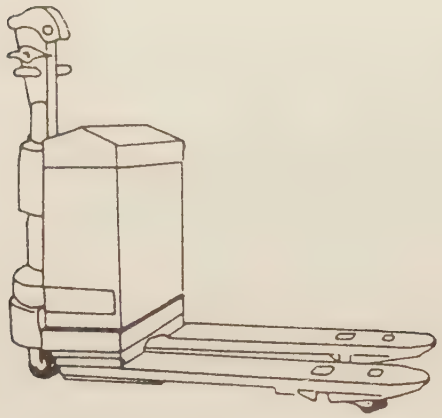


Figure 43 Pedestrian-operated battery-powered electric pallet truck

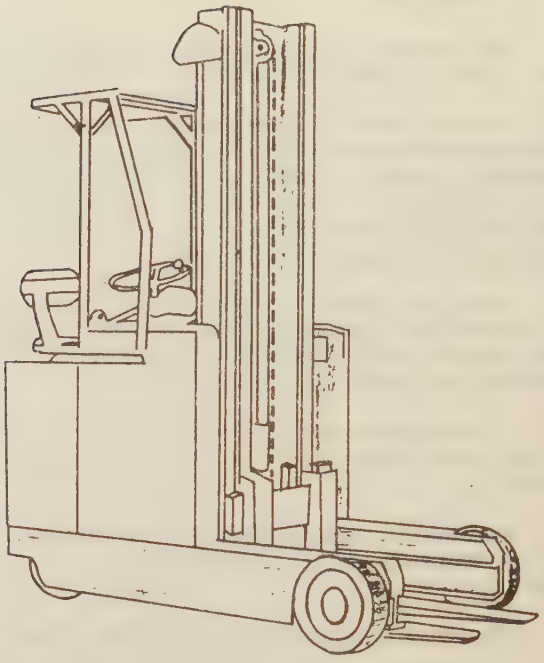


Figure 44 Reach truck

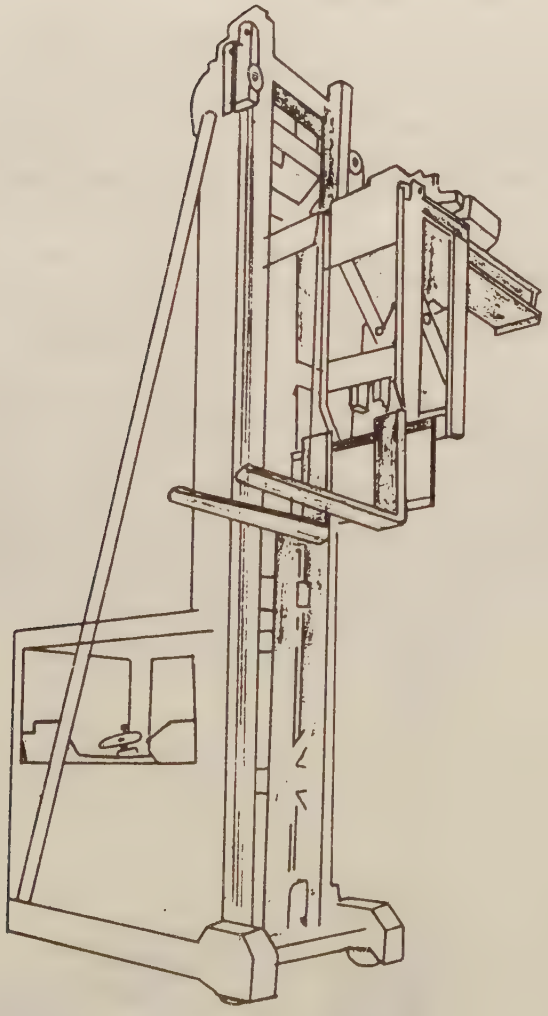


Figure 45 Turret truck

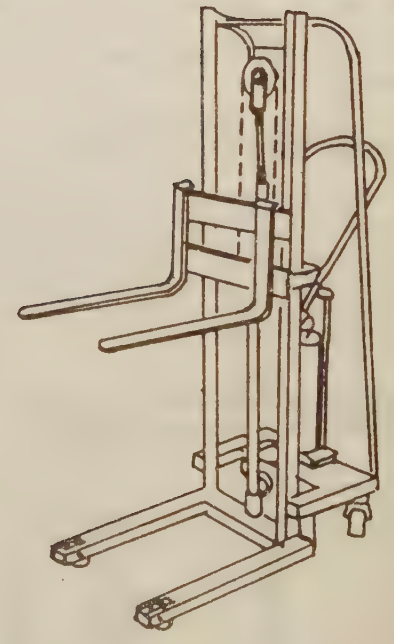


Figure 46 Hand-operated fork-lift stacker

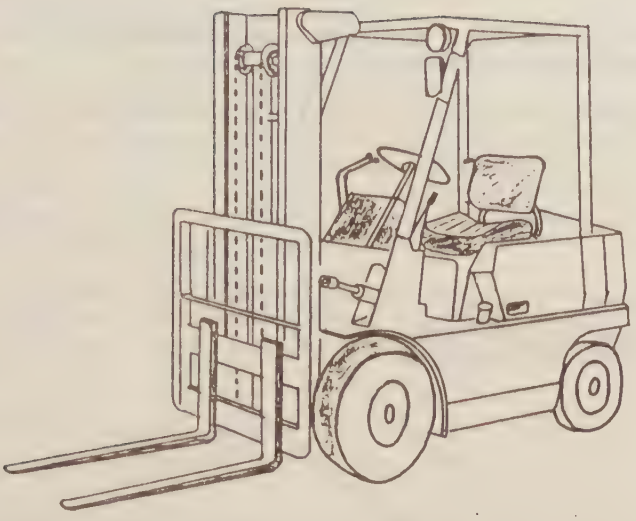


Figure 47 Fork-lift truck

When small items, such as individual cartons, have to be regularly transported in and out of the cold store, a mobile gravity roller conveyor may be used and operated through a small hatch rather than an open doorway.

Table 54

Handling equipment costs

Item	Capacity	O/A dimensions (m)	Approximate cost (US$)
Pallet	1 t	1.2 x 1.0	12
Pallet convertors	7.5 t	1.68 m high for 1.2 x 1.0 pallet	75
Hand-pallet truck	2 t	0.54 x 1.4 x 0.051 fork lowered ht	660
Pedestrian-pallet truck	1.5 t	-	4 200
Fixed racking	16 x 1 t (4 high)	5.4 x 0.9 x 6.0	750
Roller conveyor	-	0.075 pitch x 0.3 wide x 0.4 high	180/m
Power drive for roller conveyor	0.75 kW	-	600
Manual lift stacker	1 t	1.3 x 1.5 x 1.8	2 250
Counterbalanced - 3-wheeled fork-lift truck	1 t	2.7 x 1.05 x 2.0	13 500
Counterbalanced - 4-wheeled fork-lift truck	2 t	3.0 x 1.05 x 2.2	21 000
Reach truck	2 t	2.2 x 1.05 x 2.2	37 500
Battery charger (8-h charge time)	-	-	1 500

4.1.4 Insulation and refrigeration costs

The thicker the insulation the lower will be the refrigeration requirement; but the thicker insulation costs more, therefore, a compromise has to be made.

Figure 48 shows the effect of thickness insulation on costs and illustrates how a compromise may be reached.

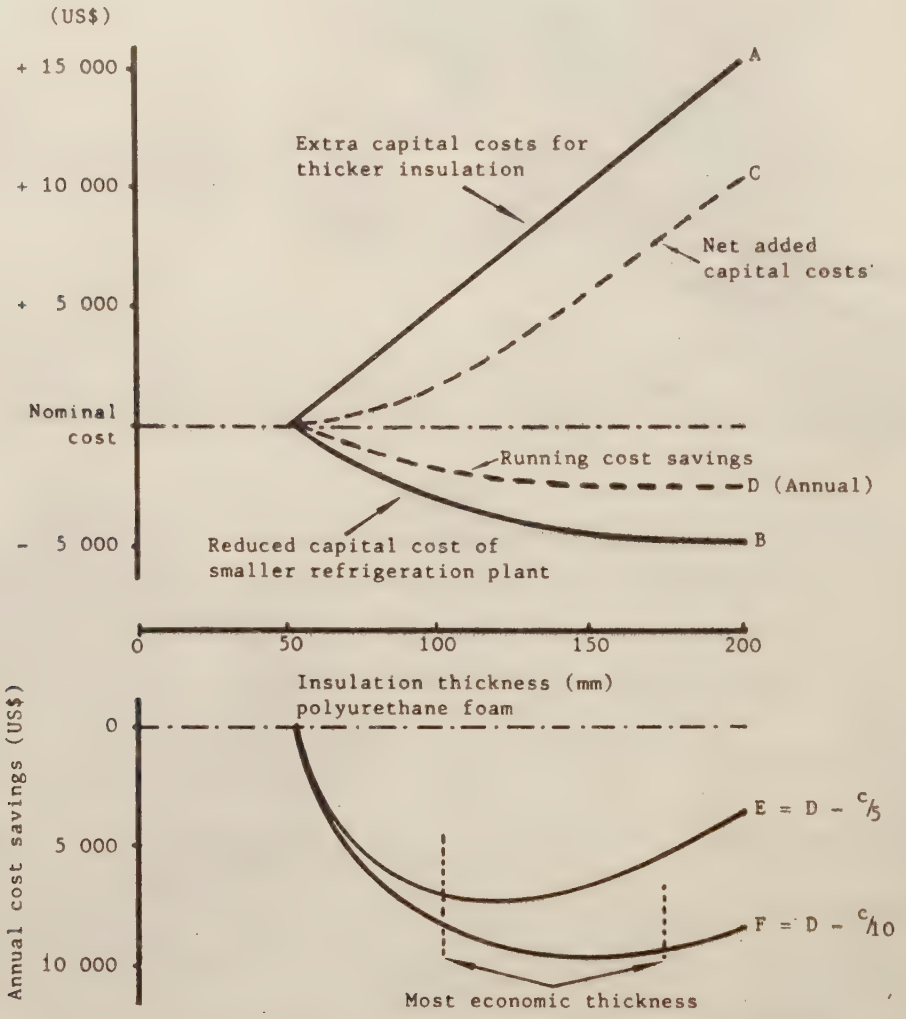


Figure 48 Economic thickness of insulation

Line 'A' is the additional cost of insulation above a given nominal minimum thickness.

Line 'B' is the savings in refrigeration equipment capital costs resulting from the reduced refrigeration requirement.

Line 'C' is derived from 'A'-'B' and, therefore, is the net additional capital cost.

Line 'D' is the savings in refrigeration equipment running costs resulting from using thicker insulation.

Line 'E' is the net annual savings when capital is written off over a five-year period.

Line 'F' is the net annual savings when capital is written off over a 10-year period.

The optimum insulation thickness, as can be seen from Figure 48, depends on the arrangement made for writing off capital costs, but this thickness will also depend on other factors such as power, insulation and borrowing costs which will, in turn, depend on local conditions. Optimum insulation thickness has therefore to be worked out on an individual basis but, in practice, likely savings may not be significant other than in the medium size or larger installations.

Whatever the resulting optimum economic thickness of insulation may be, there is a minimum recommended thickness which does not depend on costs but on the environmental conditions within and outwith the cold store. The outer surface of the insulation of a cold store will always be below the temperature of the surrounding ambient air, and if this is below the dew point temperature of the moisture in the air, condensation will occur.

The insulation thickness as given in Table 58 takes this into account as well as the likely economics but, as in the costing case shown in Figure 48, local conditions may have to be applied to determine minimum as well as optimum economic thickness. It is generally the case that the optimum economic thickness is greater than the minimum recommended thickness, but factors such as very high local costs of insulation may change this.

To avoid unnecessary condensation, cold stores should be sited where they avoid particularly demanding conditions. For instance, they should not be within a building and adjacent to a process such as the cooking of shellfish, unless the water vapour given off is ducted immediately outwith the building.

4.2 Cold Stores

4.2.1 Buildings

A good deal of the information in this section has been directly extracted from the second edition of the International Institute of Refrigeration "Guide to Refrigerated Storage", which should be consulted for more detail on both the design and operation of cold stores.

4.2.1.1 Main characteristics: Almost without exception, modern cold stores are constructed from prefabricated panels.

The laminated panels consist of a layer of insulation bound to outer and inner sheets of facing material which are usually made from a coated metal (Figure 50). The facing material gives the panel strength and also protects the insulation from physical damage. The outer sheet also provides a suitable heat reflective surface and, most important, it provides a barrier against vapour in the outside air entering the insulation and accumulating as ice. The inner surface is usually finished with a material or coating which is compatible with the storage of frozen food.

With some types of insulation, such as polyurethane, a laminated panel allows a thinner layer of insulation to be used. The insulation properties of these cellular type insulations often deteriorate with time due to the diffusion of the gases filling the voids, and the panel construction inhibits this process.

A prefabricated structure results in a very short on-site erection time and this operation can be done by unskilled labour under supervision. This type of construction is therefore appropriate for remote sites where there is no skilled labour for other types of construction.

An exception to using a prefabricated construction would be when a relatively small store is built within a building against a wall or roof so that there is insufficient room for a self-standing store. The main assurance to be given by the contractor with this type of construction is that an effective and continuous vapour barrier is provided on all the outer faces of the insulation.

Table 58 gives the likely insulation thickness required for a range of operating conditions. These are derived from empirical calculations based on a requirement for 4.6 mm of cork per 1°C temperature difference with a corresponding thickness for the other insulations in accordance with their insulation properties.

Cold Stores - evaluation of prefabricated vs. constructed on the spot

Prefabricated - advantages

(1) Homogeneous walls

(2) Easily erected store by unskilled labour under supervision

(3) Short erection time

(4) Metal-clad panels provide good vapour barrier

(5) Freestanding panels mean little additional building work

(6) Cladding can be treated (galvanized, painted, etc.) to give pleasing internal and external appearance

(7) Store can be increased in size fairly readily if required at a later date

(8) Store can be transferred to another site if required

Prefabricated - disadvantages

(1) Panels have to be factory made

(2) A high standard of quality control is necessary in order to produce uniform panels

(3) Costly equipment (presses, etc.) is required to produce satisfactory panels

Cold Store - constructed on site

Advantages

(1) Semi-skilled local labour should be capable of building store when given adequate guidance

(2) Insulation slabs (e.g., polystyrene) and other building materials are used for other purposes and are likely to be readily available

(3) They can be built to fit exactly into available space

Disadvantages

(1) Longer erection time required than for prefabricated store

(2) Untrained labour could omit necessities such as a vapour barrier because of lack of knowledge

(3) Likely to be more insulation required than in the case of prefabricated panels

(4) More supporting structure required than for prefabricated

Table 55

Cost of cold store prefabricated panels (polyurethane insulation)

Thickness (mm)	Cost (US$/m^2)
75	37.5
100	39.0
125	40.5
150	42.0

Table 56

Cold store costs (prefabricated panel stores)

Size of store (m^3)	Cost (US$/m^3)
500	55
1 000	40
2 000	30
5 000	22
10 000	18

Notes: (1) Cost includes refrigeration

(2) Cost for installation on a prepared indoor site within 250-km radius of suppliers premises

Table 57

Insulation properties

	Desirable values and properties	Polyurethane	Expanded polystyrene	Cork
Density[a/] (kg/m^3)	Low	30	20	90
Conductivity (k cal/h m°C)	Low	.0198	.030	.037
Cross breaking strength (KN/m^2 min)	High	206	170	138
Temperature limits High	Large range	+100	+93	+60
°C Low		<-50	<-50	<-50
Resistance (rot, vermin, fungus etc)	Completely resistant	Completely resistant	Completely resistant	Poor
Resistant (chemical)	Completely resistant	Resistant to chemicals, oils and solvents	Resistant to dilute acids and concentrated alkalis but not to oil, petrol, aliphatic, aromatic, and chlorinated hydrocarbons	Poor
Resistance (fire)	Completely fireproof	Normally burns but can be made in fire-proof form	Burns slowly	Burns
Remarks	No health hazards, odourless and easily worked	Can be supplied in panels, formed in place or sprayed on	Clean and easily worked, resilient	Supplied in board, granulated and bonded forms
Cost (50 mm thick) ($/m^2$)	Low	18	2.0	4.2

a/ Typical values only. Density and related values can vary widely

Table 58

Recommended minimum thickness for cold store insulation
(mm)

Material and Conductivity	Ambient Temp (°C)	Storage Temperature (°C)					
		-10	-18	-20	-25	-30	-50
Cork .037 Kcal/ hr m°C	20	150	175	200	225	250	325
	30	200	225	250	250	275	375
	40	250	275	275	300	325	425
Polystyrene .030 Kcal/ hr m°C	20	125	150	175	200	225	275
	30	175	200	225	225	225	325
	40	225	225	225	250	275	350
Polyurethane .0198 Kcal/ hr m°C	20	100	100	125	125	150	175
	30	125	125	150	150	150	200
	40	150	150	150	175	175	225

Cork thicknesses calculated as 4.6 mm/°C difference between ambient and cold store temperatures

Ratio of conductivities - cork, polystyrene, polyurethane 1:0.81:0.53

Thicknesses rounded up to nearest 25 mm

4.2.1.2 Selected stores: The capacity of a store, quoted in terms of the quantity of produce it can hold, can only be a nominal value which may differ widely from the actual capacity achieved in practice.

Some of the factors which affect store capacity are:

- loading density of the products,
- proportions of different products stored,
- stacking method used,
- stacking arrangement to meet access requirement,
- separation of products required to suit customer or product requirements,
- mixture of pallet sizes,
- handling system used and space required for manoeuvring,
- stacking height,
- space required for coolers and air-flow distribution.

The stores in Table 59 and the layout diagrams are listed under nominal capacity values which, in this case, are close to the capacity achieved by careful matching of the store dimensions to the product storage requirements.

4.2.1.3 Layout:

(i) Store height

The internal height of the cold store should be based on the height of the pallet, the number of pallets to be stacked and an additional height for safety, manoeuvring air distribution, technical installations and the ceiling structure in the case of external insulation.

In the case of stores with false ceilings, approximately 0.5-m clearance between the top of the uppermost pallet and the ceiling is adequate. Where the store is provided with internal roof/wall mounted coolers, the clearance should be at least equal to the height of the cooler in order to prevent the pallets obstructing the circulation.

In Europe, two sizes of pallets are widely used, i.e., 1.20 m x 0.80 m and 1.20 m x 1.00 m. Common pallet heights in most European countries are 1.75 m and 1.86 m, but in the United Kingdom it is 1.68 m and in Scandinavian countries 1.25 m.

For forklift truck operated stores using 2.00-m high pallets, stacking heights of 4-5 pallets are the most common. A five-pallet height should be used only for large stores with a slow stock rotation.

For four high-pallet stacking, the most commonly adopted heights for cold rooms are in the range of 7.20 m - 8.00 m, depending on the height of pallet used. If pallets are to be stacked five high, this figure may easily go up to approximately 10 m.

Whatever dimensions of width, length and height be chosen, these dimensions should be checked against existing laws, regulations and insurance requirements which may vary from country to country. One country may restrict the floor area, another the length of the room (maximum emergency distance), and in yet another the insurance company may not be willing to authorize large volumes in one room unless a high insurance premium is paid.

(ii) Store passageways

When designing cold store layouts, an important question is the width of the gangway and, therefore, the use of reach trucks is more common as they do not require gangways wider than 2.60 m - 2.70 m, as compared to 3.60 m for a counter-balanced truck.

(iii) Loading banks and antirooms

As the main purpose of a loading bank is to provide for easy handling of pallets between the cold store and transport trucks, the height of the loading ramp should correspond to the height of the floor of the more popularly used transport vehicles.

This height is normally about 1.40 m for trucks and can be as low as 0.60 m for distribution vans.

As the height of the truck floor varies with its load, it is necessary to use dock levellers between the loading bank and the truck. Depending on whether an open or covered loading dock is chosen, the dock levellers can be hung on the edge of the loading dock or built into a recess in the dock.

The length of a loading bank should enable the simultaneous handling of an adequate number of vehicles.

The width of the loading bank can vary from 4 m to 10 m, depending on traffic intensity and type of equipment used for handling.

The height between the floor and the roof is governed by the height of the forklift trucks operating on the loading dock, the height of the store doors, including the mechanism above the automatic doors, and the height of the vehicles backing on to the loading dock.

For countries which use shallow lightweight pallets, it could be economic to move two superposed pallets at a time. The height of these two pallets must then be considered when deciding upon the free height of the loading dock roof or canopy.

Cloakrooms, lavatories and offices, together with supervisor's or checker's offices, are sometimes incorporated on the loading bank at one or other end with the checker's office sited to have a good view of the whole length of the loading platform. In addition, personnel warming rooms under visual supervision can be incorporated into the loading bank.

In some instances, battery charging facilities are also incorporated on the platform, the battery chargers being mounted on the rear wall, i.e., the wall that is common to the cold store.

In other instances, it is sometimes desirable to locate the administrative offices of the complete cold store complex above the loading bank and use this as a canopy.

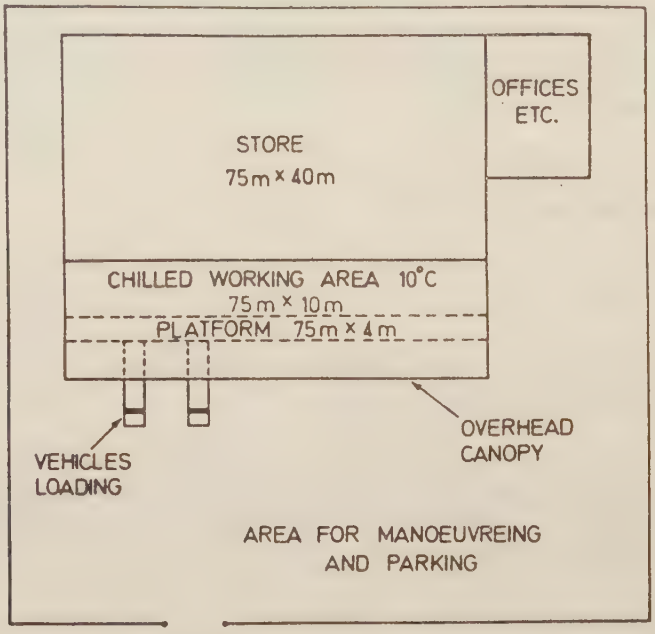


Figure 49 General arrangement for a large store

(iv) Stacking plans

In the cold-store layouts shown in Figures 51-61, the products detailed in Table 59 are used in the proportions given in Table 60.

Various combinations of access requirement, method of handling and stacking heights used, and the capacities and storage rates achieved are summarized in Table 61.

In each layout all the produce is palletized, using pallets measuring 1 200 mm x 1 000 mm x 160 mm, to give a pallet height of 1.68 m.

In all stores a substantial area is also left clear immediately inside the doorway to enable loads to be assembled and broken up. This, however, is not a standard requirement for all stores.

(v) Cold store doors

For cold stores with a high traffic turn-round, the power-operated door is best. Such doors can open or close in about 3-5 sec. Doors can be equipped for automatic opening and closing, viz., the pull cord can be positioned sufficiently far away from the door in order to allow the forklift driver to operate the mechanism. A clear door width of 2 m is suitable for normal pallet handling.

The height of the door may vary according to the height of the forklift truck or the merchandise. The door should, however, be kept as low as possible in order to reduce the entrance of warm, humid air while open. Heights of 2.40 m for hand trucks and 3.00-3.30 m for high stacking forklift trucks are normal.

When deciding upon the number of doors, one-way traffic should be considered if the traffic movement is expected to be high.

Table 59

Details of pallet loads used in layouts in Figures 51-61

Product No.	Description	Average weight/ pallet (kg)	Net storage volume/ pallet (m^3)	Storage rate (m^3/t)	Storage density (t/m^3)
1	Fish fingers	770	2.02	2.6	0.38
2	Fish steaks	730	2.02	2.8	0.36
3	IQF fillets in polytrays	326	2.02	6.2	0.16
4	IQF fillets in bulk catering pack	559	2.02	3.6	0.28
5	IQF fillets in polybags	546	2.02	3.7	0.27
6	Blocks of whole fish	990	1.6	1.6	0.62

Note: For Items 1-5 stowage rates and densities are for pallets fitted with converters

Table 60

Product composition used in the cold-store layouts in Figures 51-61

Product No.	Number of pallets										
	Store No. 1	Store No. 2	Store No. 3	Store No. 4	Store No. 5	Store No. 6	Store No. 7	Store No. 8	Store No. 9	Store No. 10	Store No. 11
1	43	43	170	180	188	100	192	175	130	310	400
2	40	40	160	160	160	100	160	160	100	160	400
3	30	30	120	120	120	70	120	120	70	120	280
4	35	35	140	140	140	85	140	140	85	140	340
5	20	20	80	80	80	45	80	80	45	80	200
6	0	0	100	100	100	260	100	100	260	100	1 020
Total pallet load	168	168	770	780	788	660	792	775	690	810	2 640

Table 61

Data on stores with different capacities and storage layouts

Store number	1	2	3	4	5	6
Nominal capacity (t)	100	100	500	500	500	500
Actual capacity (t)	102.6	102.6	507.7	515.4	521.6	502.3
Type of handling	Manual	Manual	Manual	Manual	Mechanical	Mechanical
Type of cooling	Internal coolers	Internal coolers	Internal coolers	Internal coolers	External coolers & false ceiling	External coolers & false ceiling
Total number of pallets stored	168	168	770	780	788	660
Number high	2	2	2	2	4	4
Stack height (m)	3.36	3.36	3.36	3.36	6.72 5.12	6.72 5.12
Rack height (m)	-	-	-	-	7.33	7.33
No. of pallets with convertors	168	168	770	780	416	264
No. of pallets without convertors	-	-	-	-	100	260
No. of pallets in racks	-	-	-	-	272	136
Dimensions of pallets (mm)	1 200 x 1 000	1 200 x 1 000	1 200 x 1 000	1 200 x 1 000	1 200 x 1 000	1 200 x 1 000
Internal dimensions (wall to wall)						
width (m)	12.4	9.5	20.5	25.2	14.5	24.0
length (m)	21.1	21.1	52.3	27.5	45.6	23.0
Internal dimensions (kerb to kerb)						
width (m)	12.1	9.2	20.2	24.9	14.2	23.7
length (m)	20.8	20.8	52.0	27.2	45.3	22.7
Internal height (m) (floor to ceiling)	4.73	4.73	4.73	4.73	7.7	7.7
Total internal volume (m^3)	1 237.6	948.1	5 071.3	3 277.9	5 091.2	4 250.4
Internal volume (m^3) (kerb to kerb x ht)	1 190.4	905.3	4 968.4	3 203.5	4 953.1	4 142.5
External dimensions (m) (width x length x height)						
Floor area (m^2) (kerb to kerb)	251.7	191.4	1 050.4	677.3	643.3	538
Passage widths (m)	2 & 3.9	3 & 4	2; 2.3; 2.7 & 4	2 & 4	2.7; 2.8; 3 & 4	2.7; 3 & 4.3
Total passage area (m^2)	141.2	79.2	540.4	151.2	381.5	318.3
Stowage rate (m^2/t)	2.45	1.87	2.07	1.30	1.23	1.07
Stowage rate (m^3/t)	11.6	8.8	9.8	6.2	9.5	8.2
Investment costs (US$)	62 000	49 000	132 000	99 000	188 000	177 000

Table 61 (continued)

Store number	7	8	9	10	11
Nominal capacity (t)	500	500	500	500	2 000
Actual capacity (t)	524.6	511.5	525.4	538.5	2 023.2
Type of handling	Mechanical	Mechanical	Mechanical	Mechanical	Mechanical
Type of cooling	External coolers & false ceiling	External coolers & false ceiling	External coolers & false ceiling	External coolers & false ceiling	External coolers & false ceiling
Total number of pallets stored	792	775	690	810	2 670
Number high	4	5	5	5	5
Stack height (m)	6.72	8.4 6.4	8.4 6.4	8.4	8.4
Rack height (m)	-	9.2	9.2	-	-
No. of pallets with convertors	792	405	260	810	2 670
No. of pallets without convertors	-	100	260	-	-
No. of pallets in racks	-	270	170	-	-
Dimensions of pallets (mm)	1 200 x 1 000	1 200 x 1 000	1 200 x 1 000	1 200 x 1 000	1 200 x 1 000
Internal dimensions (wall to wall)					
width (m)	18.2	14.5	19.3	18.2	28.7
length (m)	23.6	36.4	23.2	19.7	35.4
Internal dimensions (kerb to kerb)					
width (m)	17.9	14.2	19	17.9	28.4
length (m)	23.3	36.1	22.9	19.4	35.1
Internal height (m) (floor to ceiling)	7.17	9.5	9.5	8.85	8.9
Total internal volume (m^3)	3 079.7	5 014.1	4 253.7	3 173.1	9 042.2
Internal volume (m^3) (kerb to kerb x ht)	2 990.4	4 869.9	4 133.5	3 073.3	8 871.9
External dimensions (m) (width x length x height)					
Floor area (m^2) (kerb to kerb)	417.1	512.6	435.1	347.3	996.8
Passage widths (m)	2.7 & 4	2.7; 3 & 4	2.7 & 4	2.7 & 4	2.7 & 4
Total passage area (m^2)	151.6	307.3	251.1	130.5	274
Stowage rate (m^2/t)	0.80	1	0.83	0.64	0.49
Stowage rate (m^3/t)	5.7	9.5	7.9	5.7	4.4
Investment costs (US$)	150 000	186 000	177 000	153 000	264 000

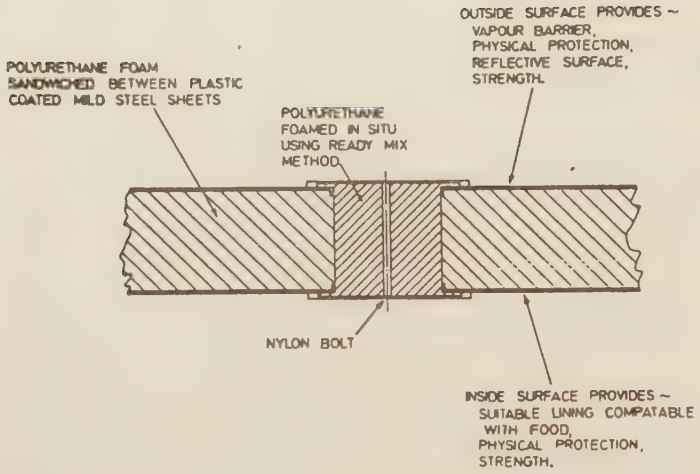


Figure 50 Typical cold-store panels

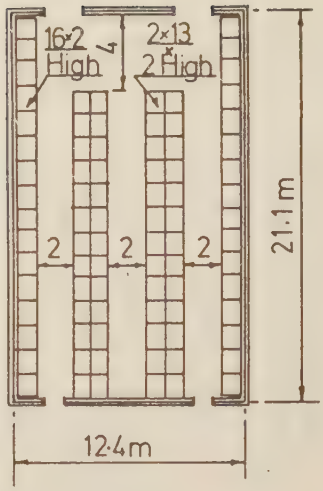


Figure 51 Store layout - 1

100-t store with manual operation.
Access to each pallet.
Pallets stacked - 2 high

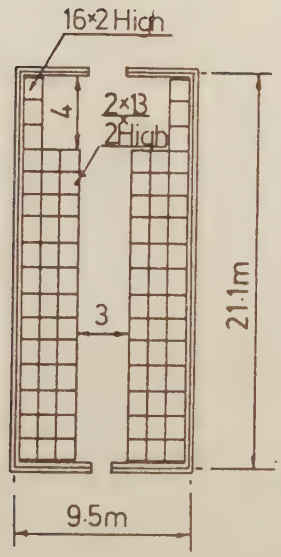


Figure 52 Store layout - 2

100-t store with manual operation.
Access to 5 different products.
Pallets stacked - 2 high

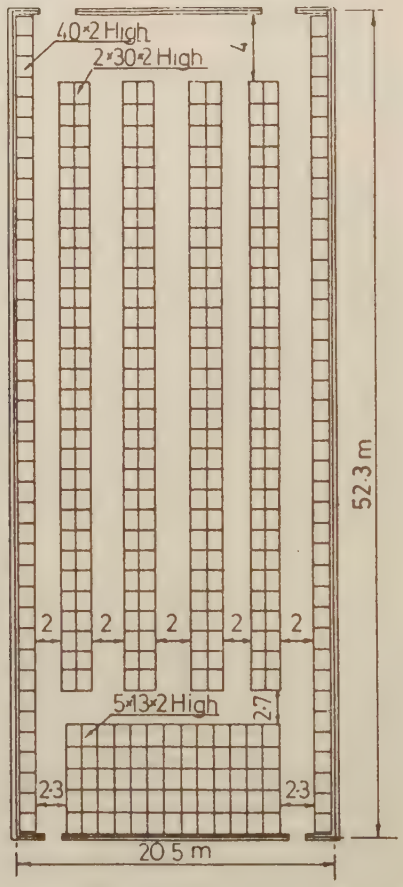


Figure 53 Store layout - 3

500-t store with manual operation.
Access to all pallets except for frozen blocks (product 6).
Pallets stacked - 2 high

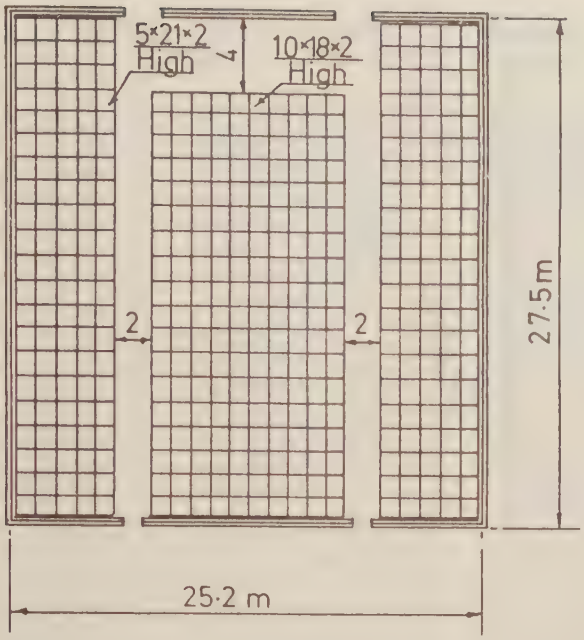


Figure 54 Store layout - 4

500-t store with manual operation.
Access to 6 different products.
Pallets stacked - 2 high

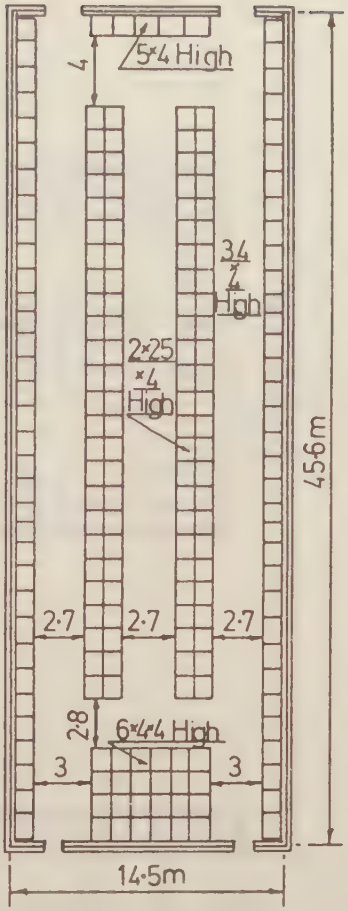


Figure 55 Store layout - 5

500-t store operated with mechanical assistance.
Access to all pallets except for frozen blocks (product 6)
Pallets stacked - 4 high

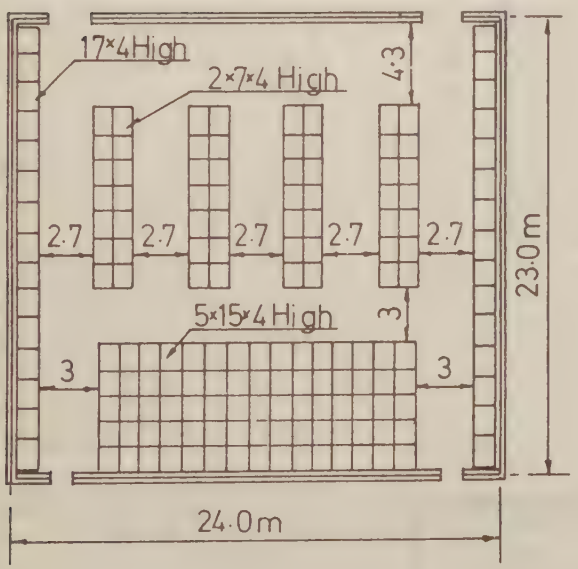


Figure 56 Store layout - 6

500-t store operated with mechanical assistance.
Access to all pallets except for frozen blocks (product 6)
Pallets stacked - 4 high

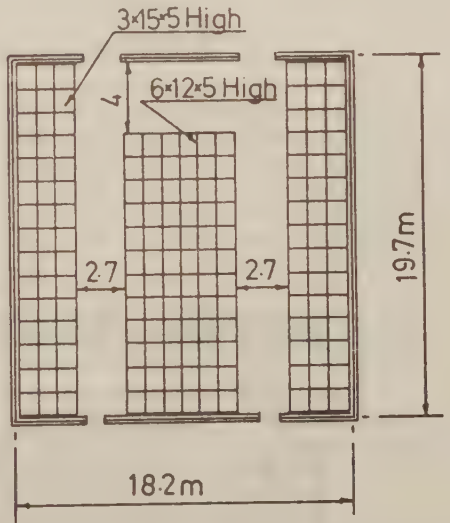


Figure 57 Store layout - 7

500-t store operated with mechanical assistance.
Access to 6 different products.
Pallets stacked - 4 high

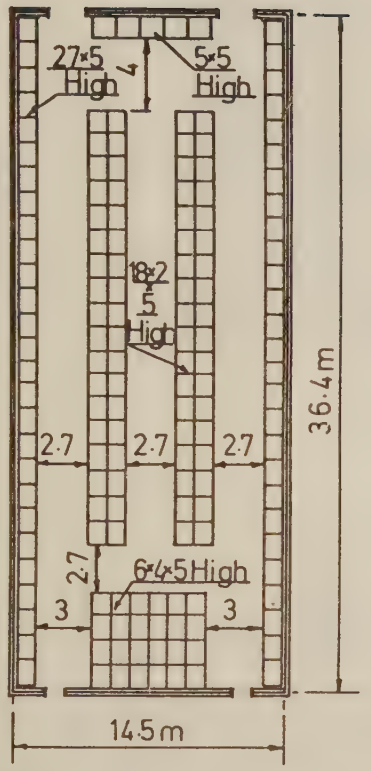


Figure 58 Store layout - 8

500-t store operated with mechanical assistance.
Access to all pallets except for frozen blocks (product 6).
Pallets stacked - 5 high

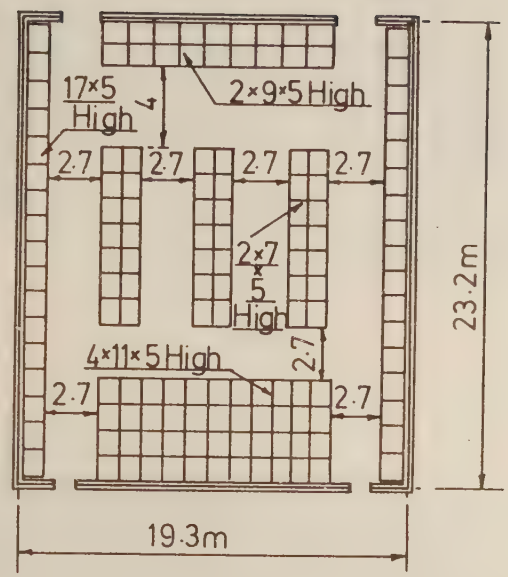


Figure 59 Store layout - 9

500-t store operated with mechanical assistance.
Access to all pallets except for frozen blocks (product 6).
Pallets stacked - 5 high

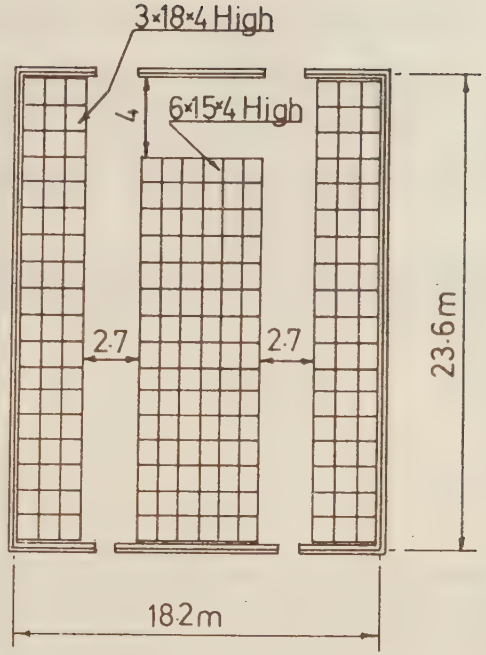


Figure 60 Store layout - 10

500-t store operated with mechanical assistance.
Access to 6 different products.
Pallets stacked - 5 high

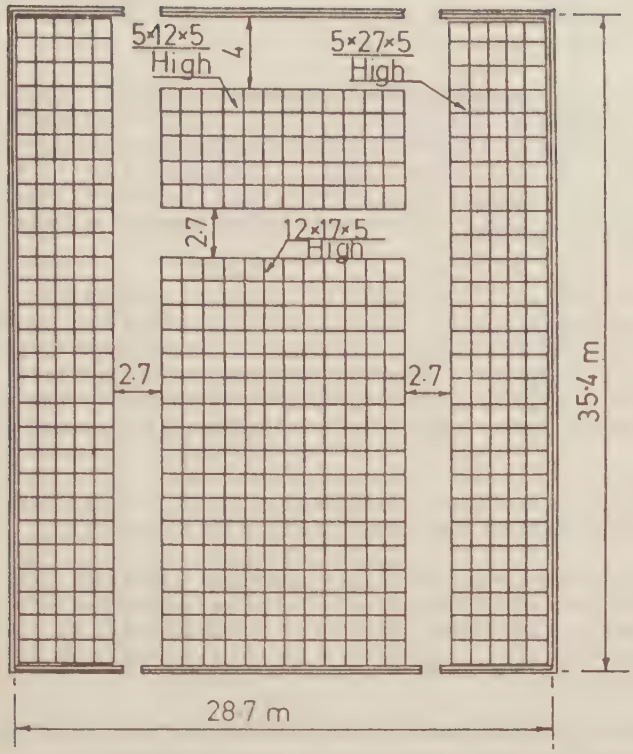


Figure 61 Store layout - 11

2 000-t store operated with mechanical assistance.
Access to 6 different products.
Pallets stacked - 5 high

4.2.2 Equipment

4.2.2.1 General: The value of produce in a cold store can be considerable, therefore, some back-up is required in case of major failure in the refrigeration plant. For instance, two smaller condensing units can be used instead of one large unit and one of these, operating on its own, may be used to hold the cold store at a reasonable temperature while the other is repaired. In larger stores, two units may be necessary to meet the refrigeration capacity required, and in this case it would not be unreasonable to have a third unit and operate any two of the three on a rotational basis, with the third unit as a standby.

Another method is to connect the cold-store refrigeration system to that of the associated freezing plant, and in an emergency, the freezer plant can be used to operate the cold store. This crossover, however, needs the attention of a skilled operator since mixing the refrigerant charges from two separate systems may not always be a simple operation.

Another system operated to ensure back-up for the cold-store operation is to have a common plant shared between the store and the freezer. This will make the operation of a multi-unit system cheaper, but this combined operation is not recommended except under special circumstances. Intermittent operation of a freezer, on the same refrigeration system as the cold store, will result in temperature fluctuations in the store, particularly with a batch-freezer operation. Freezers also require a much larger refrigeration capacity than the associated store, therefore, when the freezer is not in operation, the cold store may be operated uneconomically, with a condensing unit which is now grossly oversized.

Sharing of refrigeration equipment between the cold store and freezer is therefore only appropriate in larger systems where a number of condensing units are used and capacity can be readily matched to the demand which will vary depending on the services in operation.

4.2.2.2 Evaporators: Evaporators used for cold stores and air blast freezers are interchangeable, therefore, reference should be made to Section 3.1.2.4 and Tables 18, 19 and 20. Different criteria, however, apply to the choice of evaporator for a cold store, particularly with regard to the type of fan and defrost arrangement.

In cold stores, propeller fans can be used if the store is small; air is discharged into an open space and the cooler arrangement ensures that the maximum air-throw requirement is within the limited capability of this fan design. In larger stores, where the air throw requirement is greater or when ducting or a false roof is used for uniform distribution, aerofoil fans will be required.

All coolers can be made with the fan upstream (blow through) or downstream (draw through) of the cooler. Positioning of the fan is important and the criteria applying to cold stores is different from those applying to freezers.

In an air blast freezer, an upstream position is recommended for a number of reasons: the cooler acts as a diffuser between the fan and the produce, and this will ensure a more uniform air distribution. Heat from the fan is quickly transferred to the cooler, whereas with the fan downstream this heat will reduce the relative humidity of the air and increase the weight lost by the product during freezing. Finally, in a freezer, the air-throw capability of the fan is not important since it is a closed circuit and the pressure-drop rather than the air-throw governs the air velocity achieved over the surface of the product.

In a cold store, the air-throw requirement may be more important than other considerations, therefore, the fan may be required to be positioned downstream. However, the need should be avoided whenever possible by using a suitable cold-store layout and cooler arrangement. High humidity is also desirable in a cold store, but if all produce is suitably wrapped, this may not be critical. Cold storage space can also be saved by siting the cooler as close as possible to the wall, therefore, the fan would require to be positioned on the inside, downstream of the cooler, to allow access for repair and maintenance.

Cold stores must have an arrangement for a quick, systematic defrost, unless the coolers are plain-pipe wall grids which, generally, only require defrosting about once or twice/year.

In extreme cases, finned tube unit coolers may require defrosting a number of times/day, and this is usually done at regular intervals with a time-clock initiating a fully automatic defrost sequence. However, even in these cases, there may be times when the store is little used, at weekends for instance, and defrosting is therefore unnecessary. A manual switch should therefore be used to by-pass the clock switch during these periods.

No firm recommendation can be made about defrosting frequency other than to say that this should not be more or less often than necessary, since both extremes have detrimental consequences.

Defrosting of a cold store should not involve methods which result in the spillage of liquid within the store since this will be accumulated as ice on the floor or the produce. One possible exception to this is in large stores where a false roof or ducting is used and the cooler units are located outwith the store in an insulated space, usually at roof level, above the loading bay.

4.2.2.3 Cold-store refrigeration requirement:

(i) Sample calculation

A good deal of experience is required to make a correct calculation of a cold-store refrigeration requirement and this should therefore only be done by a qualified person. The following calculation is not complete, but it serves two purposes: it allows the reader to make a similar calculation for his own store and thereby obtain an approximate refrigeration requirement. It also helps the reader to appreciate the number of factors that have to be taken into account in calculating the heat load and, also, gives him some idea of their relative importance.

One important heat load not shown in the calculation is the heat gain due to solar radiation. This factor depends on conditions which are related to both the location of the store and its method of construction. In some cases, solar heat load may not be significant, but in other instances precautions, such as an outer cladding, may be necessary to reduce its effect. Table 65 gives allowances to be made for sun radiation when calculating cold-store refrigeration requirements.

Specification

Capacity	20 m x 10 m x 5 m = 1 000 m^3
Insulation thickness	(.2 m polystyrene or equivalent)
Total store surface area	(771.5 m^2)
Maximum ambient temperature	(+30°C)
Store temperature	(-18°C)

Table 62

Evaporator-fan data

Evaporator capacity (kcal/h)	No of fans	Type of fan	Dia (mm)	RPM	Fan motor output (kW)	Air Throw (M)	
						Blow Through	Draw Through
3 024	1	Propeller	457	1450	0.3	7.6	9.1
6 048	2	"	457	1450	0.3	8.5	9.1
9 072	2	"	610	960	0.45	9.8	12.2
12 096	2	"	610	960	0.45	9.8	12.2
16 128	2	"	762	900	0.67	12.2	13.7
18 144	3	"	610	960	0.45	12.2	12.2
21 168	3	"	762	900	0.67	13.7	13.7
24 696	3	"	762	900	0.67	14.6	13.7
28 224	3	"	800	920	1.3	15.8	15.2
32 760	3	"	800	920	1.3	16.8	15.2

Notes: (1) Capacities quoted are at 5.5°C TD

(2) Draw through aerofoil fans would give 1.7-3 times draw through values given for propeller fans

Table 63

Ceiling mounted high-capacity evaporators
(dimensions and costs)

Evaporator capacity (kcal/h)	Length (mm)	Width (mm)	Height (mm)	Approximate Cost ($)
3 024	1 245	953	782	1 400
6 048	2 007	953	782	2 080
9 072	2 311	1 029	934	2 765
12 096	2 921	1 029	934	3 450
16 128	3 226	978	1 086	4 300
18 144	3 531	1 029	1 086	4 720
21 168	4 140	978	1 086	5 355
24 696	4 140	978	1 239	6 060
28 224	4 674	1 080	1 239	6 765
32 760	4 674	1 080	1 391	7 675

Table 64

Power requirement for electrical defrosts

Evaporator capacity (kcal/h)	Electrical Load (kW)			Total load (kW)
	Coil	Drain pan	Fan casing	
024	2.2	1.1	0.3	3.6
048	4.2	2.1	0.7	7.0
072	6.3	2.5	0.9	9.7
096	8.2	3.3	0.9	12.4
128	9.3	3.7	0.9	13.9
144	10.2	4.1	1.3	15.6
168	12.2	4.9	1.3	18.4
696	14.7	4.9	1.3	20.9
224	16.7	5.6	1.6	23.9
760	19.5	5.6	1.6	26.7

Load calculation

(1) Insulation heat leak through walls, roof and floor

Conductivity of polystyrene 0.03 kcal/h m°C

Temperature difference between +30°C and -18°C = 48°C

Thickness of cork = 0.2 m

Surface area of store = 771.5 m^2

Heat leak $= \frac{771.5 \times 48}{.2} \times 0.03$ = 5 554.8 kcal/h

(2) Air changes

Average of 2.7 air changes in 24 h

Store volume = 1 000 m^3

Heat gain = (30°C and 60% RH air) 29.5 kcal/m^3

Air change heat gain $= \frac{1\ 000 \times 2.7 \times 29.5}{24}$ = 3 318.8 kcal/h

(3) Lights (left on during working day)

1 000 W = 860 kcal/h

(4) Men working

1 man working at -18°C gives off 328 kcal/h

2 men working is equivalent to 656 kcal/h

(5) Product load

5.5 kcal/kg for fish loaded at an average temperature of -11°C

Fish loaded per day = 35 000 kg

Product load $= \frac{35\ 000 \times 5.5}{24}$ = 8 020 kcal/h

(6) Fan load

4 x 0.67 kW = 3 357 kcal/h

(7) Defrost heat

1 defrost of 13.9 kW for 40 min

Recovery in 6 h = 1 328 kcal/h

Total calculated refrigeration load (sum of Items 1-7) = 23 095 kcal/h

Total refrigeration requirement with allowances = $23\ 095 \times \frac{24}{18}$ = 30 793 kcal/h

Note: It is normal practice to design a new cold store on the basis of 18 h running/24 h under full load conditions. This allows for deterioration in the fabric of the store and the refrigeration machinery over the normally expected 20 years of operational life.

(ii) Individual load calculations

Comprehensive Tables are available to simplify many of the load calculations. The method and values sometimes vary between one source and another, but the differences are unlikely to greatly influence the figure for the total load requirement. Some of the tables, most likely to be widely used, are reproduced in Tables 66-69.

Table 65

Cold store heat gain allowance for sun effect

Typical surface types	East/West Wall	North/South Wall	Flat roof
	°C	°C	°C
Dark coloured surface	5	3	11
Medium coloured surface	4	3	9
Light coloured surface	3	2	5

Notes: (1) The above allowances are added to the normal temperature difference for heat leakage calculations to compensate for sun effect

(2) The table is relevant to a location about 30° north or south of the Equator, therefore, adjustments will be required for other locations where the incidence of the sun rays may be substantially different. For example, on the Equator, the values may be increased by about 20%

Table 66

Average number of air changes/24 h for storage rooms due to door opening and infiltration

Room Volume (m^3)	Air Change per 24 h	Room Volume (m^3)	Air Change per 24 h	Room Volume (m^3)	Air Change per 24 h	Room Volume (m^3)	Air Change per 24 h
2.5	70	20	22	100	9	600	3.2
3.0	63	25	19.5	150	7	600	2.8
4.0	53	30	17.5	200	6	1 000	2.4
5.0	47	40	15.0	250	5.3	1 500	1.95
7.5	38	50	13.0	300	4.8	2 000	1.65
10.0	32	60	12.0	400	4.1	2 500	1.45
15.0	26	80	10.0	500	3.6	3 000	1.3

Correction factors: for heavy usage multiply the above values by 2

for long-term storage multiply the above values by 0.6

Table 67

Heat removed in cooling air to storage room conditions ($kcal/m^3$)

Cold Store Temp (°C)	Outside air condition		
	+20°C & 60% RH	+30°C & 60% RH	+40°C & 60% RH
-18	20.5	29.5	43.0
-25	23.5	33.0	46.5
-30	26.0	35.5	49.5
-50	36.5	47.5	62.5

Table 68

Heat equivalent of occupancy

Cold Store Temp (°C)	Heat Equivalent per Person (kcal/h)
-18	328
-25	365
-30	391
-50	494

Table 69

Heat equivalent for electric motors

Motor size	Heat equivalent under conditions of:		
	1 Load inside refrigerator box and motor outside kcal/h/W	2 Motor inside refrigerator box and load outside kcal/h/W	3 Motor and load inside refrigerator box kcal/h/W
90 W - 375 W	0.86	0.58	1.44
375 W - 2.2 kW	0.86	0.39	1.25
2.2 kW - 15 kW	0.86	0.14	1.0

Notes: (1) The heat equivalent of electric motors is made up of two components:
Column 1 - the useful horsepower output of the motor, and
Column 2 - the frictional and electrical losses of the motor.
Column 3 is the sum of these two components.

(2) Use values in Column 1 if the driving motor is outside the refrigerator and the load is inside the box: for example, if a pump motor outside the box is circulating brine or chilled water within the box.

(3) Use values in Column 2 if the driving motor is inside the refrigerator box and the load is outside the box: for example, if a motor within the box is driving a pump or fan outside the box or in another space.

(4) Use values in Column 3 if the driving motor and its load are in the refrigerator box: for example, if a motor is driving the fan of a forced-circulation unit cooler.

(iii) Compressor and condenser requirements

Compressor and condenser requirements will depend on the size of the store, the storage temperature and local ambient conditions. There are, however, other factors which will also influence the capacity requirement, and all the possible variations are too numerous to be dealt with individually. The figures quoted therefore are only correct for the conditions stated, and if they are to be used in a more general sense they should be used as a guide only.

Variations of the refrigeration load requirement for sizing the compressor for a 1 000-m^3 cold store are given in Figure 62.

The corresponding condenser load requirements for the 1 000-m^3 store are given in Figure 63. It should be noted that the values for the condenser requirement are greater since this equipment has to reject both the refrigeration and compressor heat.

(iv) Cooler requirements

The capacity figures given for coolers in manufacturers catalogues refer to the specified operating conditions only.

They are usually quoted for a temperature difference of 5.5°C (10°F), between refrigerant and air, and this condition will normally apply to most cold storage operation. If, however, a higher relative humidity is desirable to reduce evaporative weight loss from stored produce, a reduced temperature difference can be used with a directly proportional increase in cooler size.

Other factors affect the cooler capacity and some typical correction curves are shown in Figure 64.

Cooler capacity will vary with the operating conditions and typical values for a 1 000-m^3 store at different ambient and cold storage air temperatures will be similar to the compressor capacities shown in Figure 62.

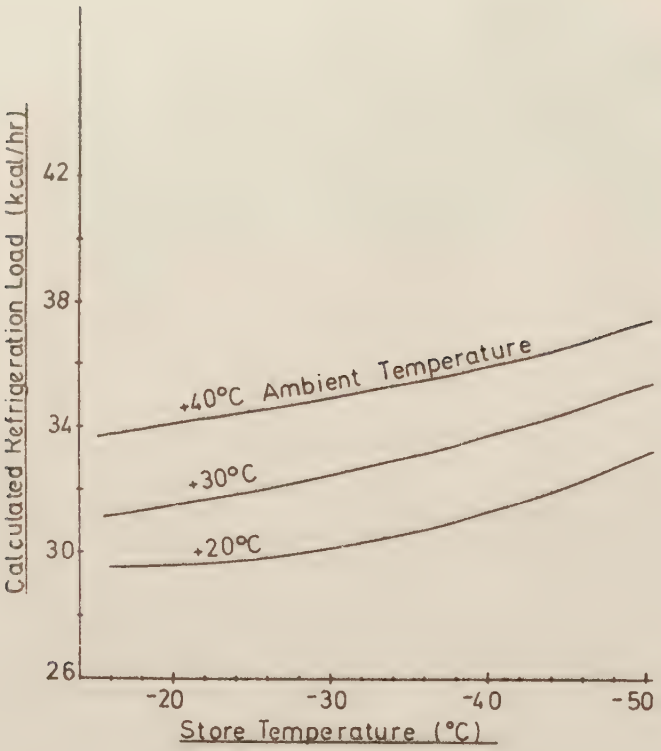


Figure 62 Refrigeration requirement for a 1 000-m^3 cold store

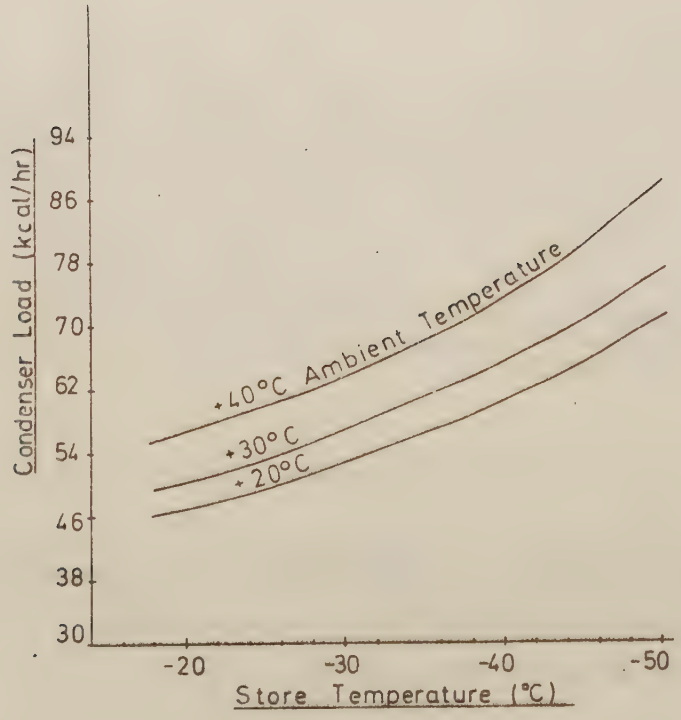


Figure 63 Condenser requirement for a 1 000-m^3 cold store

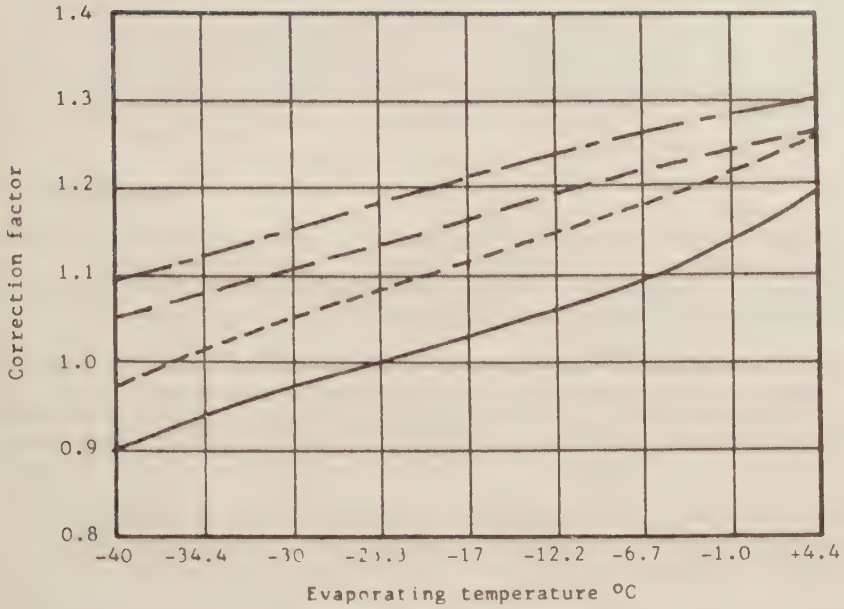


Figure 64 Evaporator/cooler capacity correction curve

Key:

— - — Pump circulation - ammonia

— — — Pump circulation - R22

-------- Dry expansion - ammonia

———— Dry expansion - R22

(v) Power requirements

When calculating power requirements, consideration has to be given to the mode of operation as well as the power requirements of the various components.

The 1 000-m^3 cold store used in the example shown in Table 70 would have two cooler units to ensure uniform cooling. However, each cooler may have an independent condensing unit or they may share a unit rated for the full refrigeration requirement. The cooler units may have electrical defrosting or alternatively, since there are two coolers, a hot gas defrost may be used.

Other variables may apply, which also affect the total power requirement of the store, therefore, detailed knowledge of the equipment and operation will be necessary to calculate accurate figures. The figures quoted in Table 70 apply to a store operating under the stated conditions only, and they represent the rated consumption figures for the equipment listed.

Table 70

Power requirements for a 1 000-m^3 cold store
(in kW)

Cold store temperature (°C)	-18	-18	-18	-25	-25	-25	-30	-30	-30	-50	-50	-50
Ambient temperature (°C)	20	30	40	20	30	40	20	30	40	20	30	40
Compressor	22.3	25.9	32.3	26.1	30.6	37.3	31.5	35.9	41.1	51.5	56.6	70.5
Defrost/cooler	13.9	13.9	17.6	13.9	13.9	17.6	17.6	17.6	17.6	17.6	21.3	19.7
Cooler fans	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Condenser fans	0.6	0.6	1.7	1.7	1.7	1.7	1.7	1.7	1.7	0.8	0.8	2.2
Under-floor and door heating	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Pump	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Mechanical handling equip.	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Total	42.9	46.5	57.7	47.8	52.3	62.7	56.9	61.3	66.5	76.0	84.8	98.5

Notes: (1) Two coolers operating with one condensing unit

(2) Cooler defrosts in sequence

(3) Total power calculated for condensing unit, plus one cooler defrost

The relationship between installed power and power consumption at full rated conditions will depend on a number of factors, and there are no widely used or accepted rules on this relationship. Electrical motor selection often depends on the range normally stocked by the suppliers, but installed power will also depend on more tangible factors such as starting loads. The peak load will, therefore, depend on the starting sequence of the equipment and this can often be arranged to reduce excessive peak loads and thereby avoid additional installation costs and also maximum demand of electrical tariff penalties.

4.3 Management

Many different routines are needed to organize, plan and control the operation of a cold store in relation to the goods being moved in and out, the refrigeration plant, handling equipment, vehicles and personnel. This is an important aspect of cold store management, particularly when the store is used for a variety of products belonging to different owners.

Goods should be readily identified and stored so that they can be retrieved in the right quantities with the minimum of effort. Temperature and other conditions relating to the quality of the goods should also be systematically recorded at the time of reception and delivery so that any defects found later can be traced to the correct source rather than this being always attributed to the cold store operation.

Systematic recording of information relating to all machinery need only occupy a short time, but it can be useful for tracing and even anticipating defects which may be time-consuming and expensive to rectify, if they are allowed to develop, and little or no information is available.

Safety standards have to be high in a cold-store operation since even minor accidents can be serious if they happen within the low temperature environment of the store. The capital invested in the building and, even more so, in the stored goods can also be high, therefore, strict fire precautions, for instance, should prevail and normal routines should ensure that this is always the case.

Some of the routines are listed, but for more details on management and safety aspects of cold storage, the IIR book mentioned in Section 4.2 should be consulted.

4.3.1 Administrative routines

- Advice note with: customer name and customer number; article name and article number; quantities (pallet/cart/weight); when will the goods be delivered/picked up; how (by train/car); who (which hauler, car No., etc.).

- Inloading/outloading:

  inloading/outloading sheets: owner of the goods; date and time of delivery; customer name/number; car or waggon number, temperature of the goods. For different articles: information about article (name and number, handling code, quantities: pallet/cartons/weight, appearance of goods and packages, temperature);

  picking lists: which articles (name, number) shall be picked, in which order they shall be picked and where they can be found;

  control;

  differences;

  weight lists;

  waybills.

- Pallet cards for:

  FIFO (First-In, First-Out);

  location;

  stock-taking.

4.3.2 Equipment routines

Two routines are important: systematic recording of information and planned inspection and maintenance.

Depending on the type of refrigeration plant installed, some or all of the following information should be recorded either continuously or at regular intervals (at least daily). A permanent record of the information gathered should be kept and should be examined at least weekly by a competent engineer.

General

Cold store temperature	(°C)
Ambient temperature	(°C)
Defrost duration	(min)
Store usage	(heavy/medium/light)

Compressor

Compressor	(No.)
Suction gauge pressure	(N/M^2)
Intermediate gauge pressure	(N/M^2)
Discharge gauge pressure	(N/M^2)
Suction line temperature	(°C)
Intermediate line temperature	(°C)
Discharge line temperature	(°C)
Compressor duty	(%)
Motor load	(A)
Motor running time	(h)

Intercooler

Line temperature in	(°C)
Line temperature out	(°C)

Liquid pump

Pump gauge pressure	(N/M^2)
Liquid line temperature	(°C)

Condenser (water cooled)

Water temperature in	(°C)
Water temperature out	(°C)

Any drastic change in operating conditions should be noted and reported immediately to the appropriate person.

Handling equipment and vehicles should have a planned inspection and maintenance routine. This can be daily, weekly or monthly, or based on operational hours or distance covered,and advice on the frequency of these operations are usually contained in manufacturers' instructions.

Good maintenance, however, has three elements which ensure that it is done:

Inspection
Recording
Checking (records and work)

4.3.3 Safety

Again, full details of the many aspects of safety are given in more detail in the IIR "Guide to Refrigerated Storage", therefore, only a list is given below as a reminder of some of the various elements that have to be taken into account when formulating safety routines.

Fire	Moving vehicles
Gas leaks	Stability of stacked produce
Flooding	Machinery guards
Power failure	Instruction and training
Protective clothing	Notices
Personnel locked in the store	Reporting and checking

5. BASIC SERVICES

5.1 Energy

An overall energy assessment has to be made in order to determine the power requirements and costs whether this is from a mains supply or by on-site generation.

Simply adding all the known power requirements for both processing and other needs, such as lighting, will normally result in an oversupply and an unnecessarily high cost, since it is unlikely that all requirements will be at maximum rating at the same time.

It is impossible to specify the appropriate allowances for the maximum demand and diversity for every type of installation since such allowances call for a special knowledge and experience, and each country may have their own standards and regulations. Standards are usually only a guide and the engineer responsible for the design has scope to increase or decrease values depending on his more detailed knowledge of the factory operation.

The first step in an energy audit will be a listing of all power requirements followed by a more detailed study of the pattern of demand. This study should also take account of daily, weekly or seasonal changes since activity and demand may vary over these periods.

At the completion of the audit, a decision is usually taken which is a compromise between cost and contingency, especially when consideration has to be given to the likely increase in energy demand due to expansion and other factors.

5.2 Quality Control

5.2.1 General

The objectives of quality control are to ensure that quality levels are maintained at an economic cost and that the product does not represent a health hazard. It is also a function of quality control to ensure that the product is consistent, particularly when it is marketed under a brand name.

The first essential in operating a quality control operation is to have a product specification and this may be set by the supplier, the customer or by legislation, standards or codes of practice.

A good quality control operation involves checking the quality of the raw material and the product at various stages of production. A final check should be done systematically and this should be regarded as confirmation that the other elements of quality control are working.

5.2.2 Requirements

Three levels of quality control have been identified.

5.2.2.1 Visual inspections: The receiver of fish at each stage of collection, processing and distribution should make at least visual inspections and keep records of their observations.

Observations that can be made are:

- general appearance of the fish or product;
- whether the fish is properly iced, chilled or frozen;
- whether there is any physical damage;
- whether the containers or packages are clean and undamaged;
- whether the species, size and other elements are in accordance with a specification or order; etc.

5.2.2.2 Quality control at the freezer complex: All goods moving in and out of the freezer complex should be subjected to quality control inspections. The following list will give some guidance on the provision of facilities for visual and other sensory checks at a large factory:

Examination room	40 m^2 floor area
Facilities	Fillet bench of stainless steel or stone sloped for drainage
	Sink for thawing samples
	Dry bench with island situation with good lighting for product inspection

Optional room	Small kitchens of about 18 m^2 for preparing cooked samples for sensory evaluation
Equipment	Household-type freezer -25°C
	House-type refrigerator 0 to 5°C
	Filleting board, knives
	100-kg weighing machine
	5-kg weighing machine
	Thermometer, -35° to 40°C
	Plastic boxes
Cost of equipment	Approximately US$ 2 500
Staff	Two

5.2.2.3 Quality control for certification: Most countries require certification of imported frozen foods and the quality control requirements for this operation will include facilities for sensory, microbiological and chemical operations. A summary of the main requirements is given below:

Examination room	40 m^2 floor area
Kitchen	18 m^2 floor area
Microbiology laboratory	25 m^2 floor area
Media preparation room	10 m^2 floor area
Chemical laboratory	30 m^2 floor area
Glassware washing room	9 m^2 floor area
Offices, stores and toilets	25 m^2 floor area
Equipment for examination	as in Section 5.3.2.2
Cost of equipment for examination	US$ 2 500
Facilities for microbiology	work benches with sinks
	furniture
	gas supply
	cupboards
Equipment for microbiology	microscope
	incubator 30° to 65°C
	refrigerator
	serological water bath
	glassware
	sterilizer
	balance ± 0.005 g
	water still
Cost of microbiological equipment	approximately US$ 9 000
Facilities for chemical laboratory	work benches with sinks
	fume cupboard
	storage cupboards
	furniture
Equipment for chemical laboratory	balance ± 0.005 g
	drying oven 50° to 200°C
	muffle furnace 1 000°C
	water bath
	extraction heater

	gas burners
	kjeldahl shelf
	distillation apparatus
	blender
	magnetic stirrer
	airejector-filter pump
	safety equipment
	glassware
	chemicals
Cost of chemical laboratory equipment	US$ 10 000
Staff for certification laboratory	six-eight

The total cost of equipping a certification laboratory, including offices, stores, will be about US$ 25 000.

Full details for setting up a model fishery products quality control laboratory are given in FAO Fisheries Technical Paper No. 107 (FIPP/T107).

5.3 Transport

5.3.1 Vessels

- Freezer trawlers for catching, processing, freezing and storage at -25°C to -30°C capacity of up to 800 t.

- Refrigerated cargo vessels (reefers), fully refrigerated, conventional, refrigerated holds; capacity of about 1 000-3 000 t at a temperature of -20°C.

- General dry cargo vessels with several refrigerated compartments or holds totalling up to between 500 and 2 000 t (depending on size of vessel), temperature controllable down to -20°C.

- General cargo container vessels with facility to accommodate up to about 400 x 20-t insulated containers, each connected to cold air supply and return manifolds which are cooled by a centralized refrigeration system. There are a series of manifolds to provide a range of temperatures down to -20°C. The containers are refrigerated by "clip on" units on shore and during long haul shore transport.

5.3.2 Vehicles

Internal collection and distribution of frozen fish requires a good deal of planning and foresight, and capital costs involved can be considerable. One of the major limiting factors in the selection of vehicles is the road network, since this may impose strict limits on the size of vehicle that can be used. In some countries, vehicles with up to 40-t loads are permissible, but in others - even when the road system is suitable - there may be limits imposed by local or national authorities. The economics of road transport generally improve with the size of vehicle, but this may also be affected by a local system of taxation or other restrictions.

To cover most likely situations that may arise and also the different requirements, such as local and long-distance haulage, three sizes of vehicle are listed below. Intermediate sizes are also readily available since individual manufacturers can usually supply a wide range of vehicles based on standard cab and engine units:

- 1-1½ t payload local delivery vans - insulated only, insulated + solid CO_2 cooling, insulated + mechanical refrigeration - mostly the latter.

Vehicle cost:	insulated only	US$ 13 500
	with mechanical refrigeration	US$ 18 000
	fuel-consumption driving	12.9-15.7 litres/100 km
	fuel-consumption refrigeration	0.9 litres/h (approximately)
	useful life	up to 160 000 km

- 3-3½ t payload short haul/local delivery truck with mechanical refrigeration. The refrigerated compartment can either be built integral with the truck body or a bolt on/off self-contained packaged unit on a flat platform lorry.

Vehicle cost:	vehicle + refrigeration	US$ 27 750
	fuel consumption driving	15.7-23.6 litres/100 km
	fuel-consumption refrigeration	1.5 litres/h (approximately)
	useful life	up to 240 000 km

- 25-t payload long-distance articulated truck with mechanical refrigeration.

Vehicle cost:	vehicle + refrigeration	US$ 65 250
	fuel consumption driving	28.3-35.4 litres/100 km
	fuel-consumption refrigeration	2.27 litres/h (approximately)
	useful life	up to 480 000 km

Maintenance costs of mechanical refrigeration can add another US$ 750-1 500/year.

If a cold store operates its own fleet of vehicles, a garage/workshop may be required. Table 71 lists equipment which may be required for this facility.

5.3.3 Cold store complex

Handling requirements at the cold store can influence the store shape, since stores with heavy traffic will require a long frontage for vehicle access. The need for quick handling in and out is also the main reason why multi-storey cold stores are now seldom built.

The unloading platform should be at least 4 m deep and protection against rain and direct sunlight should be provided by a roof canopy.

In warmer countries an enclosed handling area may also be necessary, and this should be maintained at a temperature of about 10°C. Figure 65 shows a typical plan for a service store with heavy traffic.

The forecourt of a cold store should have sufficient space for manoeuvring vehicles and, also, for parking of trucks awaiting loading and unloading.

Access road width should allow the largest trucks to pass. For example, if the truck width is 2.5 m, the access road would require to have a minimum width of 6.5 m.

5.4 Distribution and Marketing Stores

The system for the storage, distribution and marketing of frozen fish is collectively known as the "cold chain".

The importance of this "cold chain" is such that a prestudy of well defined requirements should be one of the first steps when contemplating the use of frozen storage as a method of fish preservation. This study will show what services and equipment - both in size and design - are required for a successful operation.

The two examples shown in Figures 65 and 66 represent typical home and export market storage and distribution systems, but there are many other combinations.

In Figure 65, three possibilities are shown which represent situations where there has been a different degree of development of the internal "cold chain". If this "cold chain" is not complete to the point of consumption, every attempt should be made to ensure that only the last step in handling and distribution involves the movement of a thawing product.

It can be seen that in some distribution chains, the produce is held at a number of storage points and, although this is often unavoidable, keeping the number of storage points to a minimum is one of the best ways to save energy, operating costs and, above all, maintain the high quality of the product.

Handling the produce outside the temperature control facilities should be kept to a minimum.

Ideally, the "cold chain" should be operated so that produce is not transferred from a storage space at a higher temperature to one at a lower temperature. The marketing operation should also be programmed so that longer storage times are spent in the larger, lower-temperature cold stores. The

Table 71

Equipment required for a vehicle maintenance workshop

	Quantity	Cost $
Hydraulic lift	1	9,000
Tuning equipment	1	4,500
Battery charger	1	891
Wheel balancer	1	1,620
Head lamp tester	1	747
10 tonne jack	1	783
Compressor 30 c.f.m.	1	2,668
Pneumatic tyre beader breaker	1	1,536
Pneumatic wrenches	2	1,098
Tyre levers	4	126
Trolley	1	607
Wheel alignment equipment	1	292
Air pressure gauge	1	90
Vulcaniser	1	675
Axle stands	-	90
Mechanics tools	11 (sets)	2,475
Special tools	-	1,125
Transmission jack	1	825
Mobile lifting jack	1	870
Universal engine stand	1	1,478
Drill	1	1,125
Small lathe	1	900
Electric welder	1	225
Oxy-acetylene welding set	1	675
Vice	1	112
Micrometers	-	90
Pulley extractors	-	135
Portable drill	1	68
		34,830
Contingencies for others @ 20%		6,966
		41,796

arrangements shown in Figures 65 and 66 give typical temperatures and likely storage times and it can be seen that the main bulk store can be either at the area of production or the area of consumption, and the ideal temperature progression is therefore not always achieved.

The main function of the distribution or depot store is to provide temporary storage between the main bulk store and marketing outlet. Intermediate stores will also require facilities to allow large consignments to be broken down for final distribution, and it is important that arrangements are made in the design and layout for this operation to be done under conditions not harmful to the product. In tropical countries, for instance, it may be necessary to provide a refrigerated annex to the store for handling and sorting. The requirements for handling and ease of access for the selection of produce are probably more demanding at the distribution store than at the main bulk store, therefore, the storage density is less and the cost of storage proportionally higher.

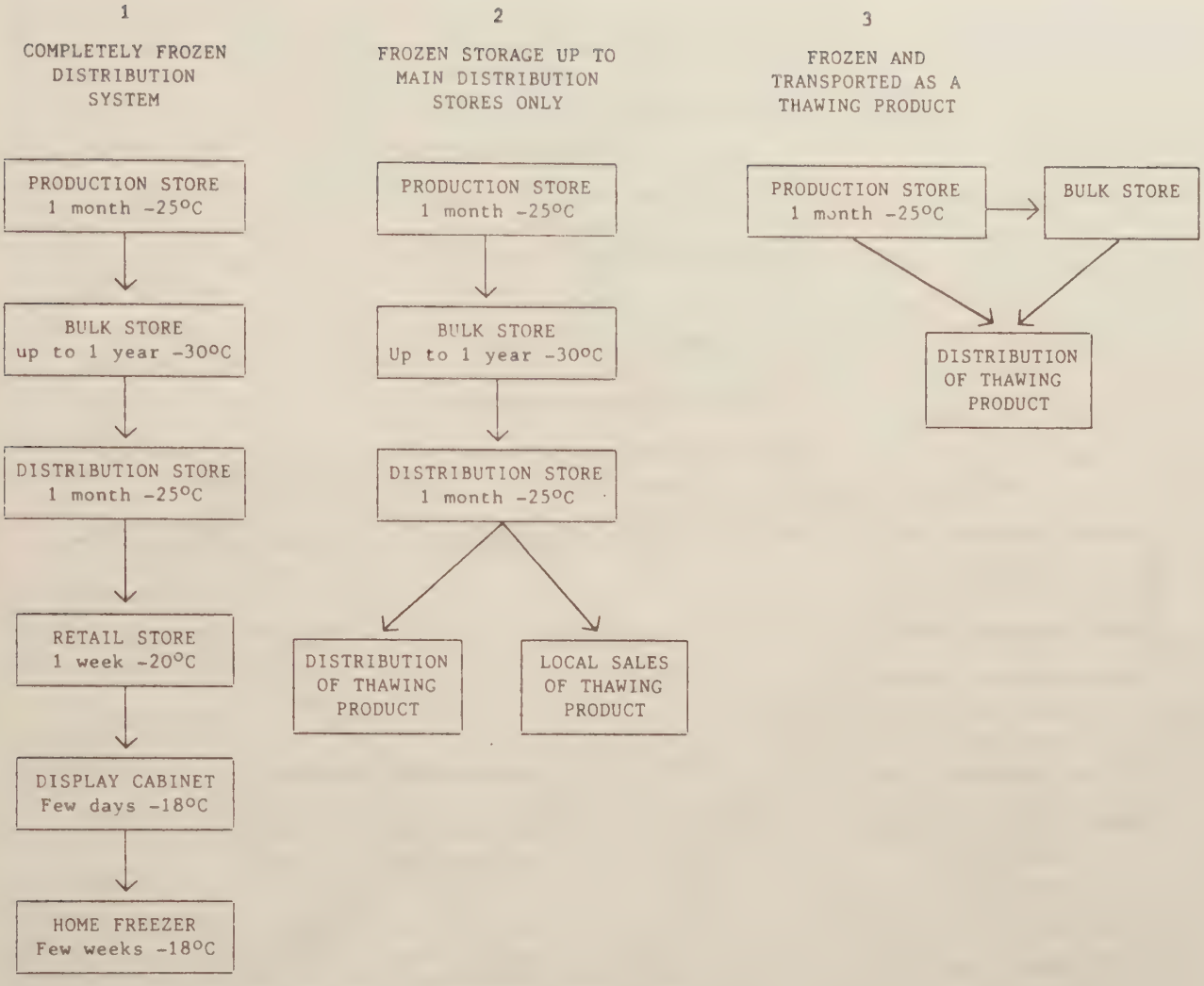


Figure 65 Typical storage and distribution systems for home markets

Note: Storage times are the likely maximum at each stage, but the total storage time need not be the sum of all the stages

The optimum size of a distribution or depot store can only be determined after a careful pre-study of each individual case. Some of the factors to be taken into account are:

the movement of goods in and out of the store and the probable storage times;

peak requirements due to seasonal and other factors;

size and frequency of loads;

the mix of goods to be stored and the likely storage density;

requirements for ready access to the products stored;

separation requirements between different products;

sorting requirements within the store;

buffer requirements to offset likely delays in supplies.

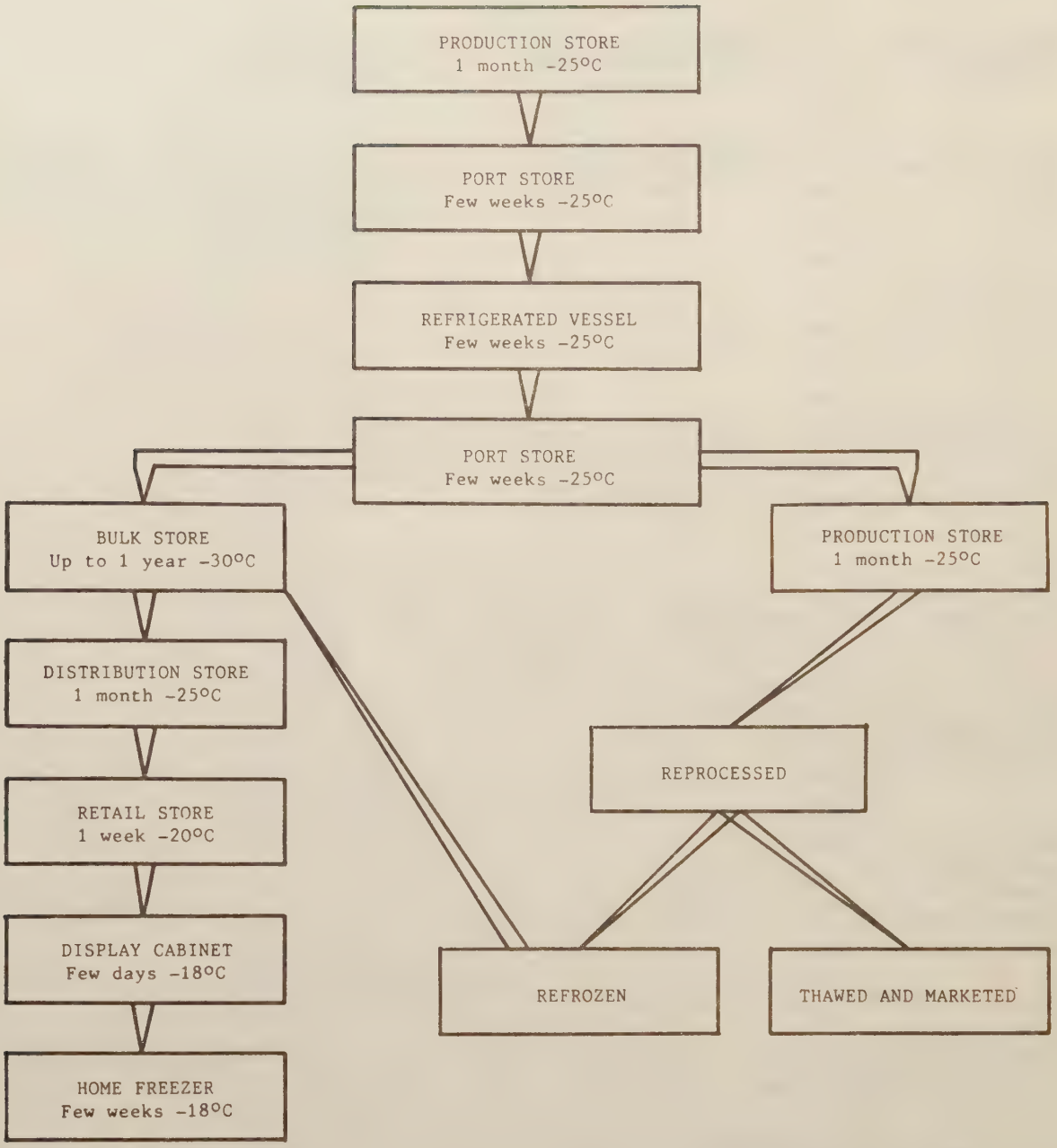


Figure 66 Typical storage and distribution system for export market

6. LAYOUTS AND CONSTRUCTION WORK

6.1 Typical Layouts

6.1.1 General

It is unlikely that in any situation there is only one ideal layout for the processing area, but at the planning stage an attempt should be made to conform with some fundamental requirements. Two main considerations are hygiene and economy, and since there is seldom scope for a compromise on hygiene, this aspect should always be given priority. Other requirements are often in conflict, therefore, a compromise has to be made depending on the importance of the different elements in the local situation.

Factory layout depends on the building available and particularly on its size and shape. It is therefore more likely that a good layout will be achieved with a new building than by converting an old one, and this consideration may influence the decision on the choice of building and site.

Some of the factors to be considered, when planning factory layout, are listed below but others, which may depend on local conditions, may be equally important, particulary those relating to building regulations and other relevant legislations.

- The layout should be arranged so that raw material and finished produce are kept apart, thus avoiding the possibility of cross-contamination.

- Processing after a cleaning or washing operation should be kept apart from pre-cleaning processes.

- The layout should ensure that drainage is always away from the finished product and other clean areas.

- "Wet" areas used for washing, icing, machine processing and other operations should be kept separate from "dry" areas, such as those used for weighing, packing and labelling.

- The layout should allow easy access to all equipment for effective cleaning and maintenance.

- Equipment using refrigeration should be sited so that a common plant room can be used for machinery which is not an integral part of the equipment.

- Delivery and dispatch of raw material and finished goods should be kept separate to avoid contamination and also traffic problems.

6.1.2 Shrimp processing

Depending on the size of shrimp and the availability and cost of labour, shrimp may be processed by mainly mechanical or manual methods.

A suggested factory layout for processing 800 kg/h of small-to-medium size shrimp using a machine peeling operation is shown in Figure 67. Prior to planning a factory layout, a flow chart should be prepared and the diagram relating to this operation is shown in Figure 68.

Larger shrimps are more likely to be suitable for processing with a mainly manual operation, and a typical layout together with the corresponding flow chart are shown in Figures 69 and 70.

6.1.3 Whole fish processing

In this case, a more elaborate flow chart - Figure 71 - has been prepared showing the different operations and the movement of produce and materials such as packaging and ice. The term "whole fish" can cover a wide variety of species and products which may require different prefreezing and post-freezing treatments, therefore, the layout in Figure 72 only represents a typical case incorporating many of the elements associated with good practice.

6.2 Building

6.2.1 General

If new premises are to be constructed, or major alterations have to be made to an existing building, much of the detail in design and layout will be governed by local building regulations and the special requirements of the user will therefore have to be incorporated within these restraints.

Higher standards of hygiene, improved handling, more economical use of space and lower costs for heating or air conditioning can be achieved if all operations are confined to one building.

Fish handling should preferably be confined to the ground floor only since this will make good drainage easier and cheaper, structural costs will be reduced and the main working area will be more accessible to vehicles and thus ensure quick handling and avoid delays.

6.2.2 Walls

Walls should be smooth and waterproof.

Brickwork or blockwork of dense concrete blocks are preferable for the main walls since they provide a good base for a smooth washable finish; exposed steelwork must be protected against corrosion and may also need a coating that prevents condensation. Steel reinforcement should be covered with at least 40 mm of concrete.

One satisfactory wall finish is obtained with ceramic tiles. These are expensive, and if tiling to the full height of the wall is out of the question, then fit tiles to a height of 1-1½ m

Table 72

Factory details for shrimp processing and freezing

Process and capacity	Total factory area (m^2)	Factory subdivisions		Temperature (°C)
		Category	Area (m^2)	
Machine peeling and freezing shrimp 800 kg/h	600	Miscellaneous processing	494	+15
		Chilling	42	+1
		Cold storage	64	-30
		Office accommodation and associated facilities		
		Plant room/workshops		
Hand peeling and freezing shrimp 250 kg/h	432	Miscellaneous processing	390	+15
		Chilling	22	+1
		Cold storage	20	-30
		Office accommodation and associated facilities		
		Plant room/workshops		

Table 73

Factory details for whole fish freezing processing

Process and capacity	Total factory area (m^2)	Factory subdivisions		Temperature (°C)
		Category	Area (m^2)	
Blast freezing whole fish 250 kg/h	640	Miscellaneous processing	378	+15
		Chilling	16	+1
		Cold storage	143	-30
		Office accommodation and associated facilities	59	+17
		Plant room/workshops	44	+15

and have a cement rendered finish above. The top edge of the tiles should be finished with a rounded tile, or the tiling made flush with the wall surface above.

The walls should be kept free of unnecessary projections; pipework should be sunk flush with the wall surface or neatly boxed in.

Jutting corners susceptible to damage from passing traffic should be protected by a steel plate, especially where the wall is finished with tiles. Corners between walls should be rounded off.

Whatever the decorative finish, a cement-based rendering on the brickwork or concrete block wall is desirable to give a smooth, easily cleaned surface that can be hosed down. Cement paints and chlorinated rubber paints stand up well to wet conditions; wherever higher resistance to water and brine is needed, epoxy, urethane and neoprene paints should be considered and the manufacturers' recommendations complied with. Distempers are not very suitable. Always use light colours.

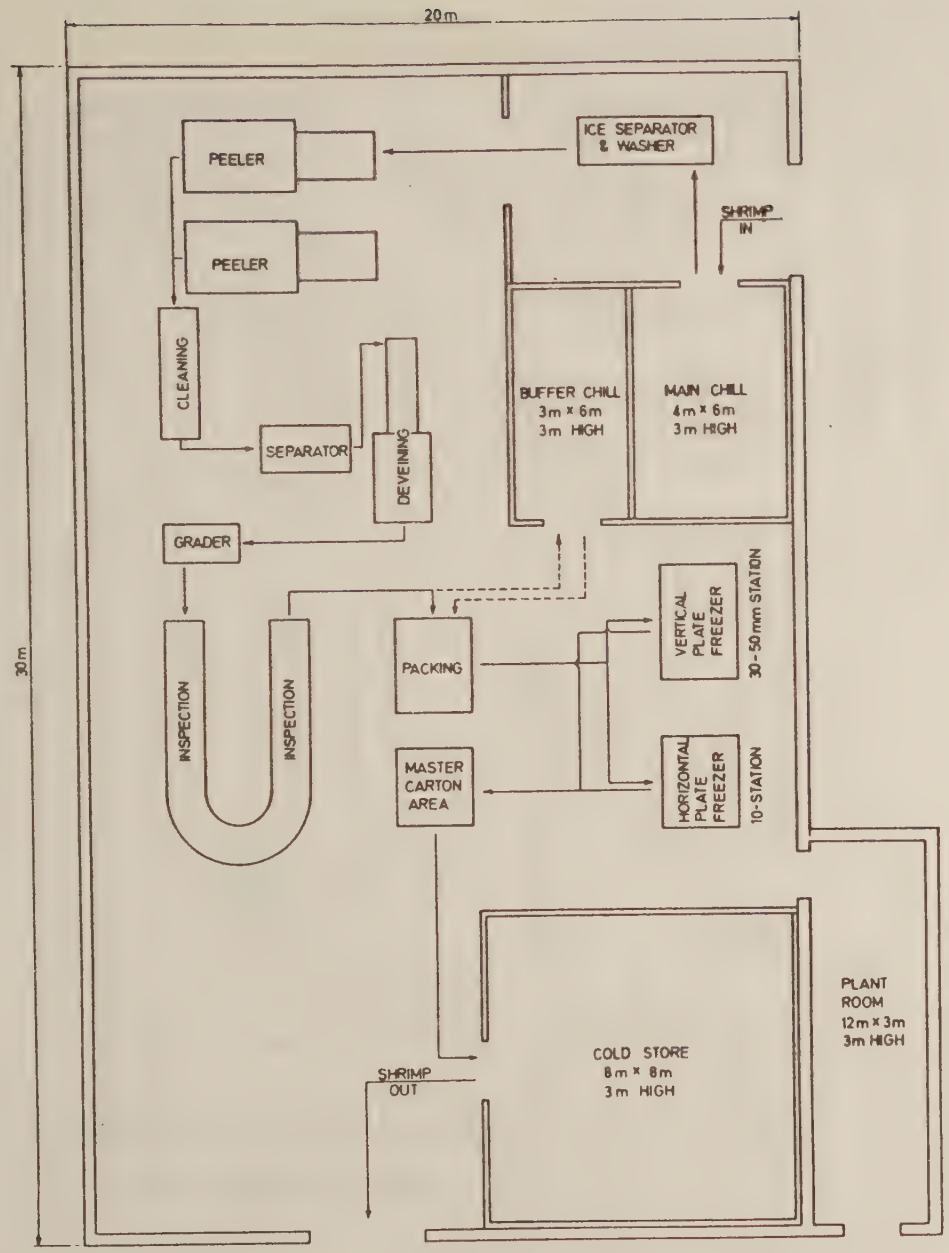


Figure 67 Proposed layout and flow plan for 800 kg/h medium and small shrimp processing plant

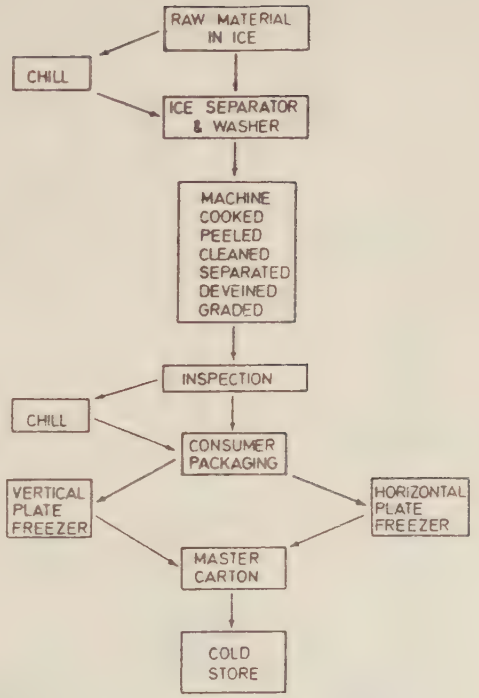


Figure 68 Flow chart for processing medium and small shrimp

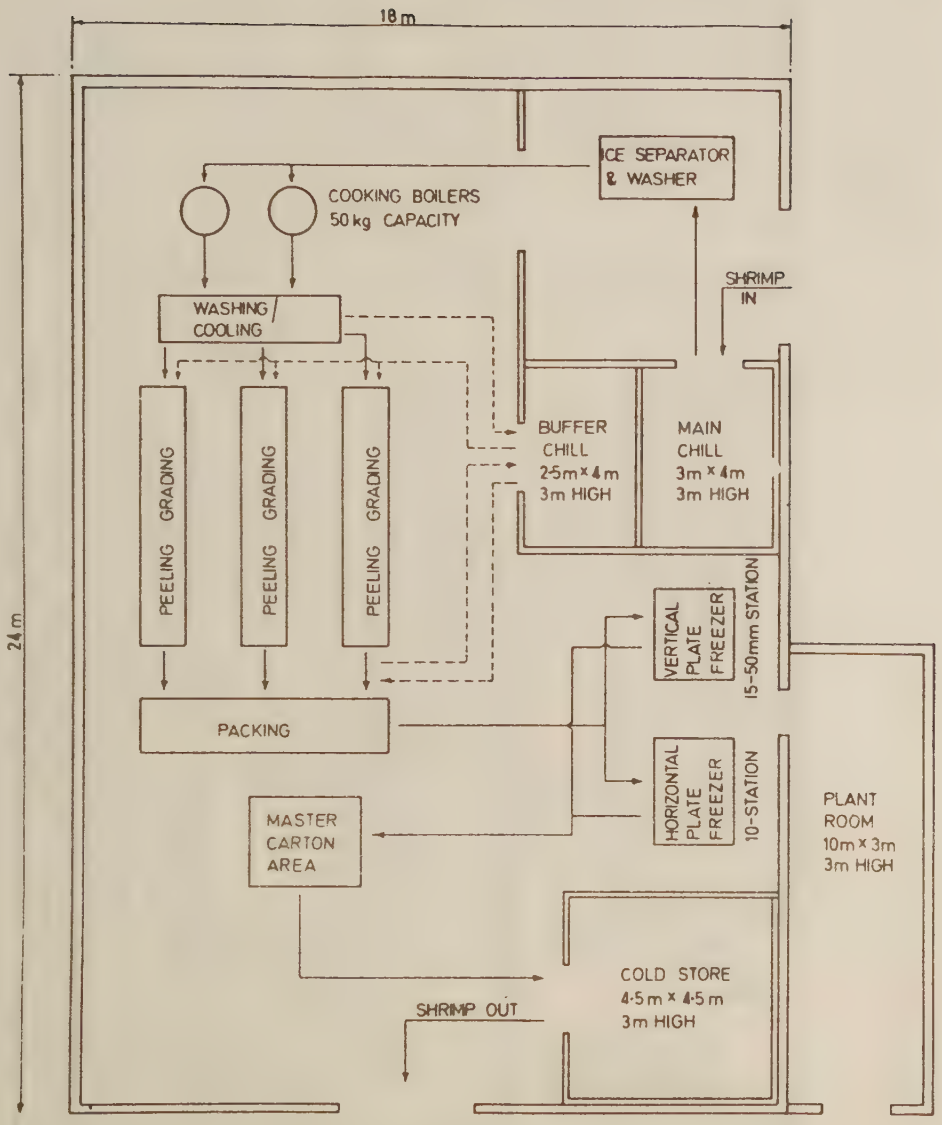


Figure 69 Proposed layout and flow plan for 2 t/day hand-peeling shrimp-processing plant

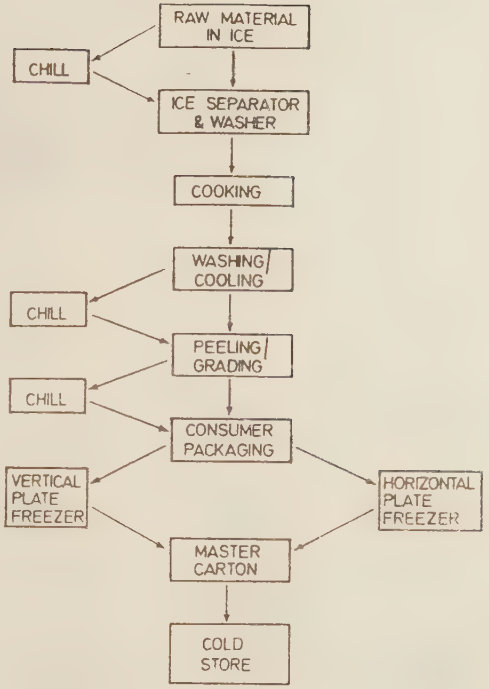


Figure 70 Flow chart for processing large shrimp

Material Flow Diagram For ABF - Whole fish factory

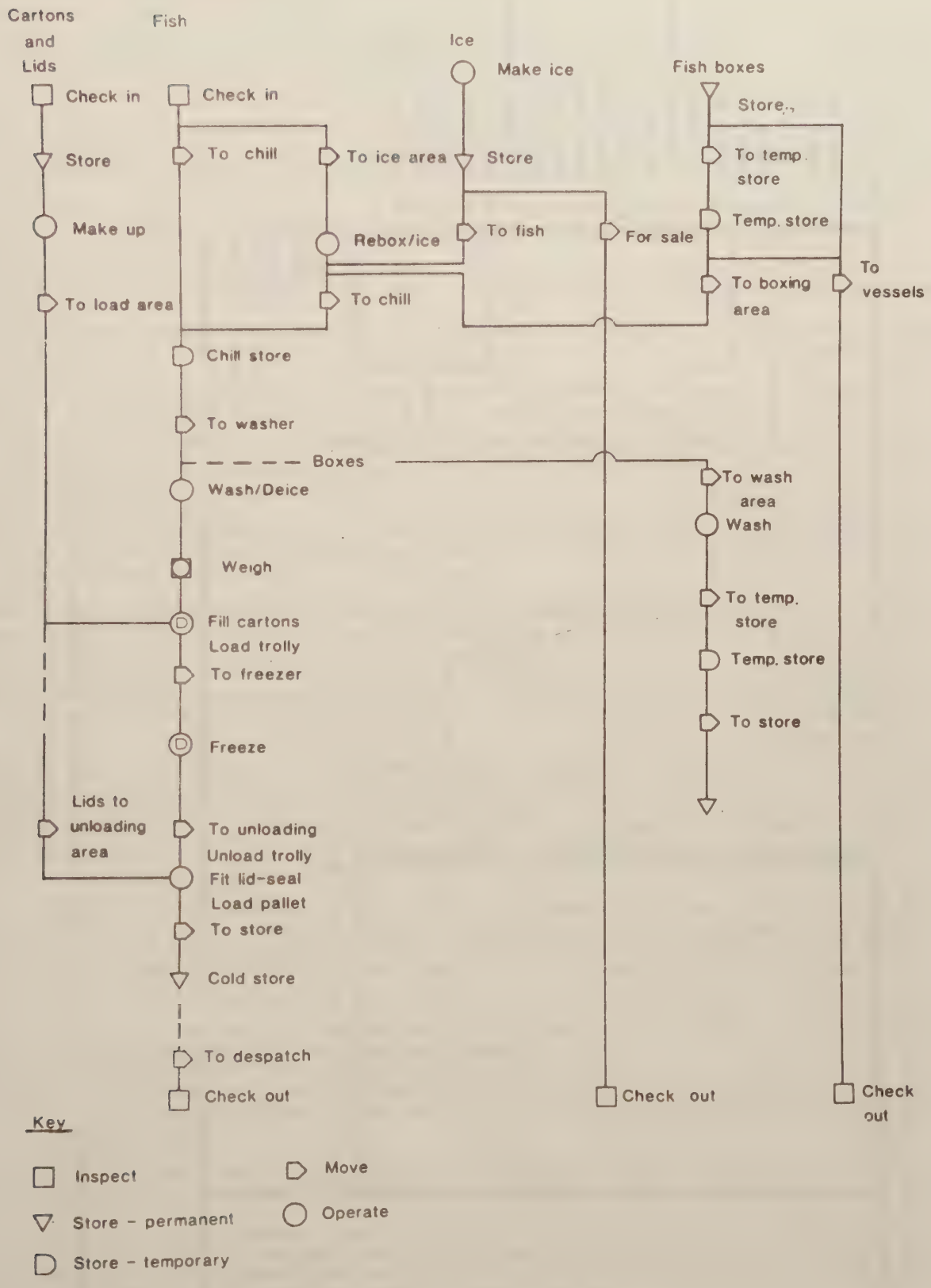
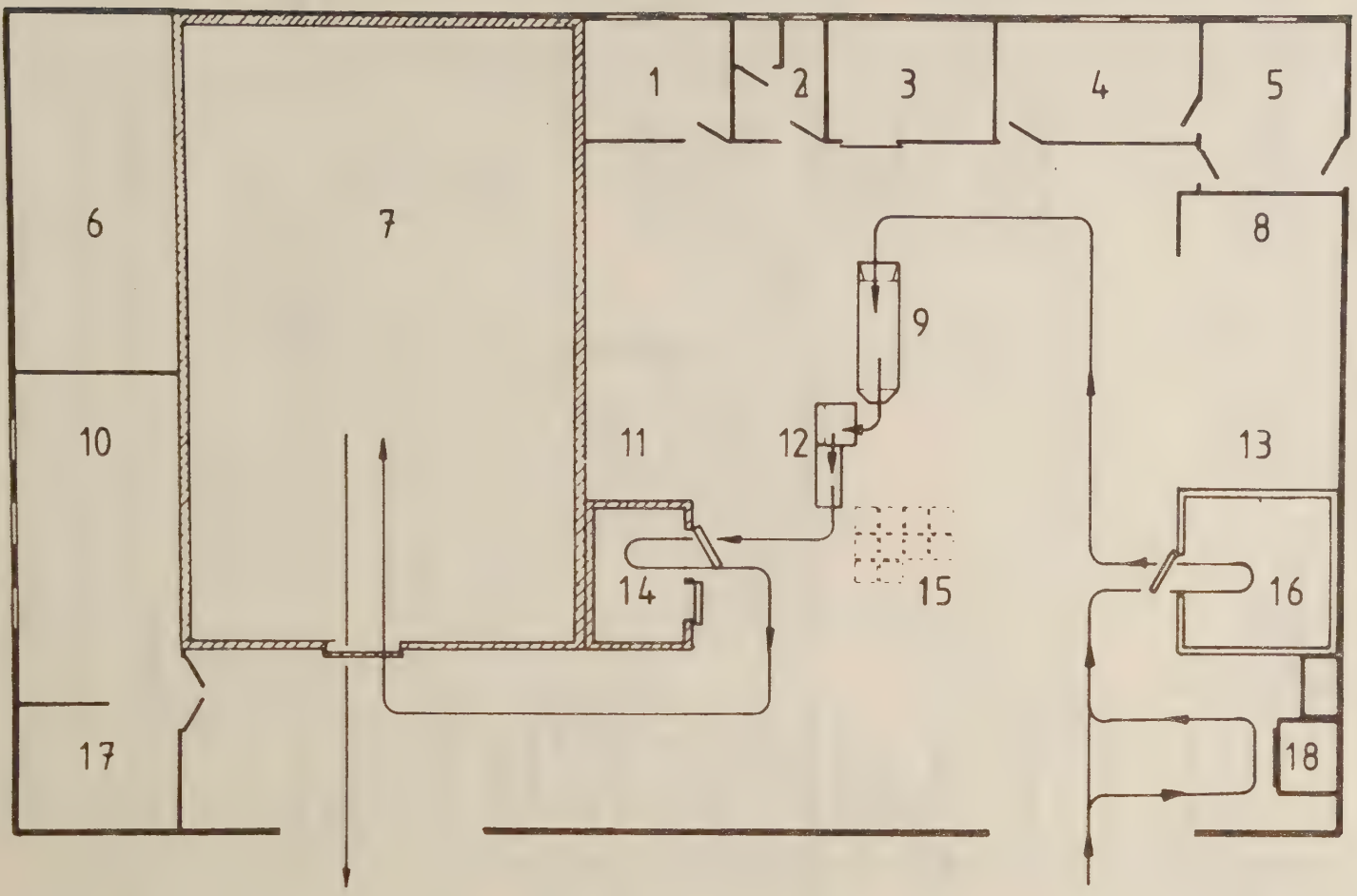


Figure 71 Flow chart for whole fish freezing



Key

1 Rest Room
2 Toilet
3 Dry Store
4 Office
5 Entrance
6 Engine Room Expansion
7 Cold Store 100-150t
8 Box Storage & Washing
9 Washing/de-icing
10 Plant Room
11 ABF Expansion
12 Weighing & packing
13 Chill Store Expansion
14 ABF
15 ABF trollies
16 Chill Store 4-6t
17 Workshop
18 Ice Plant & Store

0 1 2 3 4 5

Scale of metres

Layout of 2 t/d whole fish blast-freezing factory
— space allowed for expansion

Figure 72 Proposed layout for whole fish freezing

6.2.3 Floors

Floors should be hard-wearing, non-porous, washable, well drained, non-slip and resistant to possible attack from brine, weak ammonia, fish oils and offal.

Concrete is attacked by fish oils and also by the continued action of strong brine; it is also attacked by acids but not by ammonia. The rate of attack depends on the density of the concrete and on the amount of wear that removes the attacked material to expose fresh material; thus, when concrete is used as a floor finish, it must be of high quality. If the surface is subject to very heavy wear, by iron-wheeled bogies for example, then concrete is not very suitable.

Clay tiles or paviors make the most hard-wearing floors for fish-working spaces. They should be about 50 mm thick and laid flush in jointing made from furane or cashew-nut cement. Latex cement may be substituted as a cheaper jointing material, but is not quite so satisfactory.

Avoid severe damage to floor surfaces by reducing necessary dragging of equipment and dropping of boxes; fit your trunks and trolleys with synthetic rubber-tyred wheels instead of steel ones.

Surface dust is sometimes a nuisance on an otherwise good quality concrete floor; treatment with sodium silicate solution or with magnesium or zinc silco-fluoroide solutions is often effective.

When traffic is not too heavy, and a more decorative surface than concrete is required, terazzo tiles can be fitted.

Sheet finishes, such as rubber or PVC that have to be stuck down, are usually not suitable for fish-working floors. Rubber is attacked by fish oils, and PVC swells when wetted.

Asphalt flooring is not resistant to oils and fats, and is rather soft; it is, however, not slippery when wet, is fairly hard-wearing and waterproof. It is suitable for premises handling white fish where traffic is not severe.

An alternative to the installation of an expensive flooring material throughout is to fit very hard-wearing tiles at the points of greatest wear and to fill in the remainder of the area with granolithic concrete.

Make new floors sturdier than the present traffic demands if there is any likelihood of heavier equipment, such as fork-lift trucks, being introduced later.

Loading bays that are subject to extra heavy traffic may require the use of special metal tiles with an infilling of concrete; the anchor plate type is suitable. As far as possible, loading bays that are continually open should be completely screened from the working area of the factory.

The hard, smooth finishes that are most easily cleaned and best withstand hard wear are usually slippery; it is often necessary to compromise. A certain amount of ribbing in the floor surface may be necessary, but the best safeguard is regular washing and scrubbing of the floor. If ribbed tiles are used, the grooves should run down the drain slope. Some clay tiles are supplied with a specially roughened non-slip surface, and carborundum can be incorporated on granolithic finishes. Avoid sudden changes from one floor surface to another that has a different degree of slipperiness; the danger of staff slipping is greatest where two such surfaces adjoin.

Fish working floors are continually being wetted, hence adequate drainage is essential. A slope of 1 in 100 is usually enough, and the slope should be so arranged that the regular traffic of men and vehicles is across it, not up and down; there is then less danger of accidents. Slopes greater than 2.5 in 100 are dangerous, therefore, the slope of the floor should be between the foregoing limits.

Take care to avoid any area of floor surface on which stagnant pools of liquid can lie; surface attack can be greatly accelerated under these conditions.

All junctions between floor and walls should be covered and made watertight, thus eliminating corners that cannot easily be cleaned. Where possible, the floor material should be carried up the wall for a short distance.

All floors should be vermin and insect-proof; joints around pipes and fitments that pass through the floor should be filled with impervious material, such as hard cement or pitch mastic.

If a floor other than the ground floor of a building has to be used for wet fish processing, such a suspended floor needs a waterproof membrane or underlay between the structural floor and the finish of tiles or concrete; suitable materials for such a layer include acid-resistant asphalt and bituminous felt. Expert advice should be sought to ensure that such a floor is laid in a proper manner to protect the structure below.

6.2.4 Ceilings

Ideally, the ceiling should be a continuous, smooth, unbroken surface that can be easily cleaned, for example, the underside of a concrete slab. If, however, there is a roof space containing beams, trusses, service piping or machinery, then a suspended ceiling is desirable unless the building is very high.

Ceiling boards should be unaffected by moisture; asbestos-based boards are unsuitable.

Condensation may be troublesome in cold weather because of the high humidity within the building; insulation should be provided above the suspended ceiling and the roof space well ventilated to the open air. Some forced warm-air ventilation may be needed in extreme cases and expert advice should then be sought.

Insulated ceilings can be finished with a hard gloss paint in a light colour.

A suspended ceiling that is not insulated should be constructed of an absorbent material, such as plaster, and finished with a soft non-washable distemper; absorbent colour washes of this kind should be washed off and renewed once every six months.

Where the roof beams or trusses are exposed, that is where no suspended ceiling is fitted, paints for the steelwork should be chosen carefully to avoid the risk of flakes falling into the factory. Aluminium structures cost more but can be left unpainted.

The clear internal height must suit the factory production and storage, and its adequacy for all future requirements should be considered.

The plant must be accommodated with sufficient clearance for its installation, removal and maintenance, while mobile equipment, such as fork trucks, may call for special headroom for efficient working. Any tendency for a given type of production machinery to increase in height should also be considered when deciding on the clear height for the framework of a factory building.

Ancillary equipment nowadays is commonly slung from the roof structure; this may increase the height requirement.

Storage space afforded by an increase in the vertical direction will probably prove cheaper to provide than the equivalent obtained by increased floor area.

6.2.5 Doors and windows

Doors and window frames should be of non-porous, non-absorbent materials; wood is not very suitable.

Doors should be made without inset panels or ledges; a flush surface is much more easily kept clean. Doors should be self-closing and the bottoms protected by kicking plates.

Window frames of a suitable aluminium alloy need no painting, but regular washing is needed to keep the metal bright and to prevent pitting corrosion. Steel windows must be heavily galvanized and kept well painted, both to protect the metal against corrosion and to reduce the risk of paint flaking.

Wooden doors and window frames should be kept well painted.

Flyproof screens of 8-mesh British Standard wire gauze should be fitted to doors and windows during the summer months; flyproof doors should be self-closing.

6.2.6 Lighting

Good plant lighting will allow workers to do their jobs properly without strain, and expose dirt and other sources of contamination.

Maximum use should be made of natural daylight by providing adequate windows and skylights.

Good diffused general lighting to augment or replace daylight is best achieved with fluorescent lights.

A light level of 500-750 lux is usually sufficient, depending on the difficulty of the visual tasks done in the factory.

Coloured lights decrease rather than increase a person's liability to detect colour differences in foodstuffs.

General lighting should be augmented, where necessary, by individual lights at weighing and inspection points for example.

Light shades and fittings should be of simple design and easily cleaned.

6.2.7 Ventilation

The atmosphere in fish plants is humid; good ventilation will reduce the nuisance of condensation, remove bacteria-loaded moist air, dust and smells.

Good temperature control can provide comfortable working conditions without allowing air temperature to rise too high and so rapidly spoil the product.

Windows and skylights can be used for ventilation, but judicious use of exhaust fans or special roof vents is preferable.

Ventilation ducts should be fitted within walls or ceilings, or held well clear on bearers to allow for easy cleaning. The inlets should be insect-proof and away from dusty places. All metal fitments that are likely to rust should be well protected by paint. Screens should be removable for cleaning.

A mechanical air conditioning system can be installed to control temperature and humidity, in which case a competent heating and ventilating engineer should be consulted.

6.2.8 Drains

Floor drainage channels should have easily removable gratings and should be wide enough to permit brushing out.

Main drains should not connect directly to a sewer without an intermediate trap, and should be large enough to carry away all waste water without choking or flooding. Traps should be readily accessible for cleaning and have properly fitting inspection covers bedded in grease.

6.2.9 Power supply

Make provision not only for present but for likely future requirements of electricity when wiring the building; install wiring of ample capacity in proper conduit, and fit plenty of power points in convenient places. All power points should be properly earthed and made waterproof wherever necessary; they should comply with existing electrical regulations.

6.2.10 Water supply

A generous supply of water must be available at numerous points throughout the premises, both for use during processing and for cleaning. Storage tanks should be kept covered.

Staff should not wash in sinks and tubs that are used for processing; hand-wash basins should be located where they will be regularly used by fish workers, preferably in the fish-working space itself, in addition to, or instead of, those adjacent to lavatories.

6.2.11 Factory yards

The whole yard should have an even, impervious surface and be properly drained. If returnable fish boxes are stored and washed there, the walls adjacent to that part of the yard should be cement rendered to a height of at least 1.5 m. Adequate clean, dry storage should be available for box storage, preferably under cover; new boxes and other packaging materials should be stored inside the building.

All offal bins, which should have close-fitting, deep-lidded lids and should preferably be stored in close out-buildings, should not be left exposed in the open yard. If they must be stored in the open, they should be kept in a cool, shady place, either on a smooth concrete plinth, or supported at least one foot clear off the ground on a metal stand so that the paving beneath can be cleaned. The whole stance should be protected by screening walls, and be properly drained.

6.3 Site

6.3.1 Location

The following list is not comprehensive, but it gives guidance on some of the factors that may have to be taken into account when selecting a site for a freezing and cold storage complex:

The cost of land

The location of the site with respect to raw material supplies

The continued availability of raw material supplies

The location of the site with respect to markets and other outlets

Are there likely to be local objections to the complex

Will local conditions add to the building costs

Local rates and taxes

Local grants or other aids available

The cost of site preparation

Availability of sufficient water of the right quality

Adequate power supplies

Are there nearby ancillary support services such as ice plants

The cost of disposal of liquid and solid waste

Is there land and other services available for future expansion

6.3.2 Site level

A flat, level site is preferable since this is likely to result in lower site preparation costs. However, the cold-store floor level may be raised to provide a suitable loading bank of about 1.4-1.5 m high for vehicles. On sites where there is likely to be problems with ground flooding, it is essential that the cold store in particular is kept above the maximum level likely. Elevating the cold store above ground level also allows natural air ventilation to be used to prevent "frost heave".

For some of the reasons given above, other floor levels in the complex may also be elevated above ground level, but on some sites a two-level system may be contemplated since some of the needs of the processing area are best served by a ground-level floor.

6.3.3 Communications

The availability of suitable communications is often the major consideration when choosing a site both for the movement of goods and for other services such as labour.

Ideally, the site should be close to the source of raw materials, which means that it should be near the point of off-loading from fishing vessels. However, a major portion of raw material supplies may be consigned from more distant ports and it may therefore be advantageous to site the complex on the periphery of an urban area to ensure easy vehicle access.

If goods have to be loaded on and off a vehicle for delivery to the complex, it is usually of relative unimportance whether the journey is very short or say 5 km, since the time spent on loading and unloading accounts for most of the costs.

It is also often more important to have good communications rather than short journeys, since this will govern the size of loads to be carried and also transport times.

When journeys are long it may also be necessary to contemplate the cost of breakdowns in communications or the cost of ensuring that there are adequate contingencies to cope with these situations.

6.3.4 Site size

Adequate space for vehicle access and manoeuvring is of prime importance, and an area outside the main buildings may also be required for the storage of pallet frames. Vehicle size and the type of operation will be decisive when planning the layout and size of the site, as also will the need for future expansion. Modular store construction allows cold store expansion to be achieved by adding on to existing stores, and the site arrangement should allow this to be achieved with similar standard-sized units.

Parking space for other vehicles and equipment should also be adequate since if no allowance is made they often interfere with the cold storage and factory traffic.

7. COSTING AND CASE STUDIES

7.1 General

Accurate costing can only be done when local requirements, prices and economics are known. Costing can also be involved and complicated in order to benefit from any concessions likely to apply, therefore, final calculations should be done by a competent person familiar with local conditions.

Prices and costing methods used in this document should therefore only be used in the absence of more precise instructions, since they are only likely to provide a crude guide for provisional budgeting purposes in most situations.

During the planning stages of a project, a number of costings require to be made to determine the overall viability of the project and also to make comparisons when a choice exists between using different types of equipment and processing methods. Preliminary costings also allow the effect of all likely variations on prices and profits to be assessed, and the longer term viability of the project can thereby be determined.

7.2 Case Study

7.2.1 General

One approach, when making a case study, is to use costing methods to compute the prices that have to be paid to the fishermen for raw material supplies. For this purpose, an Internal Rate of Return (IIR) is assumed and discounted cash flow techniques are applied to compute the amount available each year for the purchase of fish and hence the price per ton that can be paid.

Using the basic model, the sensitivity of various changes, such as the selling price of the finished product and labour costs, can be tested and allowances can thereby be made for variations that are likely to apply.

Before examining in detail the various investment possibilities, planners should be aware of certain important characteristics. Firstly, fish supplies are heavily dependent on the weather and this may result in wide variations in the catch on both a daily and seasonal basis. Secondly, the relation between the effort that is expended in gathering fish and the actual yield is rather tenuous and only experience will give correct values.

Glut and periods of shortages are common and this may greatly effect the economics of the processing and freezing operation.

The introduction of a fish processing complex in a new area may impinge on traditional rates and patterns of activity in the community and this will have to be taken into account at the planning stage.

The new complex may itself overstimulate the fishing effort, and since fish stocks are finite, consideration will have to be given to this and other wider effects that may result from the implementation of the proposals.

The operation requires a high investment involving considerable risks, therefore, it will be necessary to ensure sustained effective management in order to realize the anticipated benefits.

7.2.2 Cost model

7.2.2.1 Prawn processing: The model used in the case study is based on a prawn processing and freezing operation and the principles and methods involved in the costing exercise will be substantially the same for other products and processes.

The main elements of the prawn processing operation are shown in the flow diagram, Figure 73.

The process has been designed to produce blocks of prawns frozen in trays in horizontal plate freezers. This is a widely used method of freezing which allows the product to be frozen with water added to form solid blocks, which is a form of presentation required by many importers.

The production of whole frozen prawns makes allowance for 5% waste/loss, thus 237 t of raw material requires to be purchased to sustain an output of 225 t of whole frozen prawns.

In the headless frozen prawn calculations a yield of 60% is assumed with an overall waste/loss of 5%, thus 394 t of prawns have to be purchased to sustain an annual output of 225 t of headless, raw prawns.

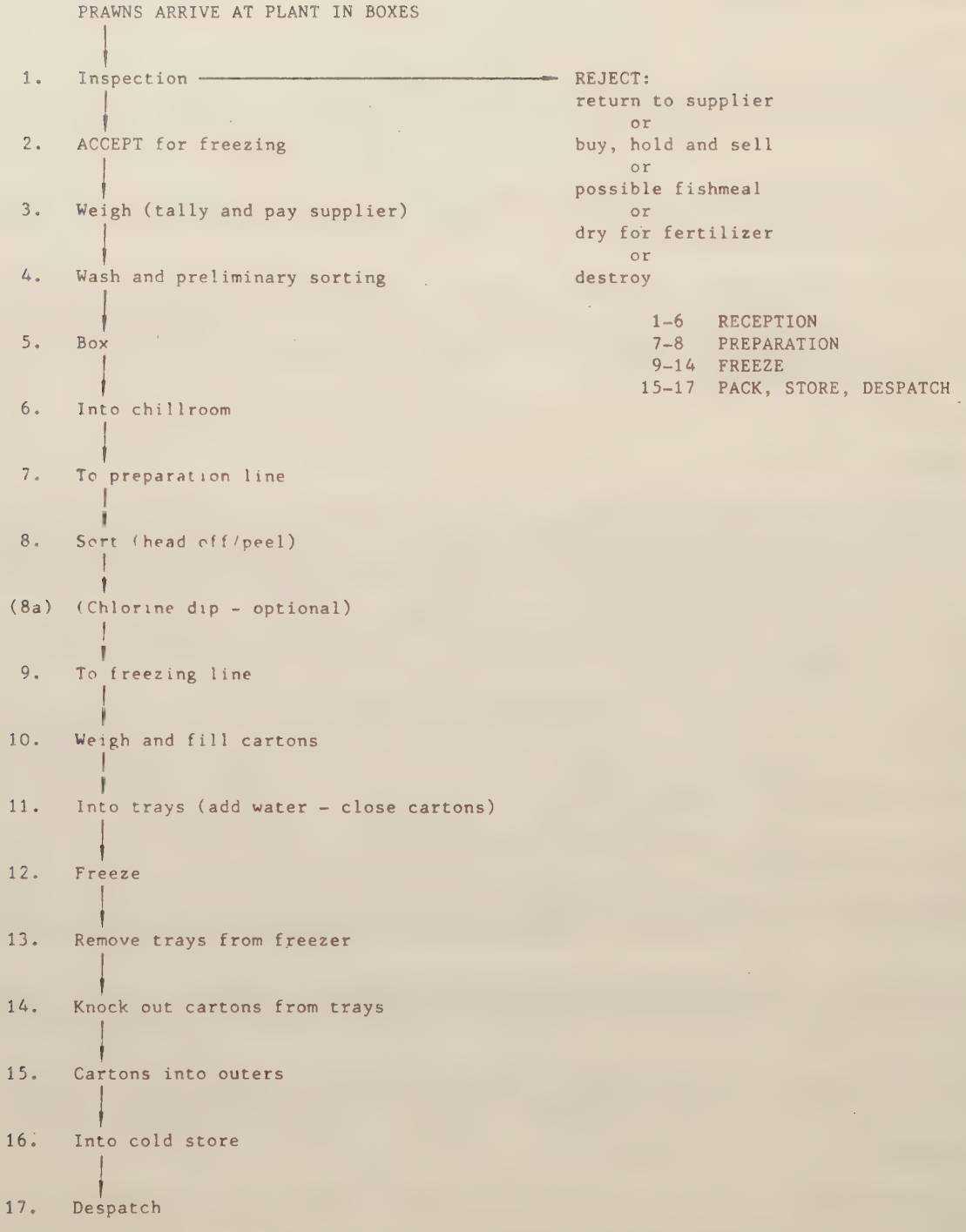


Figure 73 Product flow for prawn processing

7.2.2.2 Equipment:

(i) Chillroom and cold store

Each point is equipped with a refrigerated chillroom for storing iced prawns prior to processing and a low-temperature cold store for the finished product. Chillroom capacity is generous and allows for the storage for up to 10 days supply of material. The reason for this is that although this storage time would not be recommended for prawns prior to freezing other fish are often caught as a by-catch and some of these may be stored prior to dispatch to local fresh fish markets or other processing lines.

The cold store is designed to hold up to one month the output of finished product which is the maximum holding time usual in production cold stores. Longer storage times should therefore involve the use of better equipped and larger bulk stores.

(ii) Ice plant

A flake-ice plant has been included in the model, but this may not be necessary in some situations where adequate supplies of ice are available. In the model it is assumed that three parts of ice to one part of prawns is required for cooling and keeping the prawns chilled from the time of catching until they are frozen. Ice requirements, however, are generally less for cheaper fish products, and they will vary depending on the time and temperatures involved and also re-icing requirements.

(iii) Fish boxes

The costs include the supply of an appropriate stock of high density polyethylene fish boxes and that rental fees to fishermen would be sufficient to offset replacement costs, and thereby no allowance is made for replacements.

(iv) Freezer trays

Two sets of trays have been allowed to enable one lot to be packed and prepared while the other is frozen.

7.2.2.3 Working system: It is assumed that the plant operates with two eight-hour shifts on 250 days/year. In situations where there is a shorter working year due to the seasonal nature of the fishery, consideration should be given to operating a three-shift system to optimize the use of plant and equipment and reduce overhead costs per unit weight of product. A number of other operational patterns are possible, but in a model - whatever pattern is used - it is assumed that the chillroom and cold store facilities are operational at all times.

7.2.3 Comparative costing

When costings are made to compare one type of equipment with another, or to determine the effect of changes in operating conditions, it is important to ensure that all relevant costs are included and that the conditions applied are applicable to the situation under consideration.

Manufacturers' costs tend to be for conditions which favour their own equipment and they are also likely to quote figures based on the best performance rather than those relating to average commercial operating conditions. Another recent trend is to use computer predictions rather than practical measurement for determining data used in costing and, again, this information may not be realistic. Since published figures are likely to be unreliable, comparative costings are more likely to be accurate if they are based on previous experience with the same, or similar, equipment. The following are some of the situations which may arise, that are known to give inaccurate or misleading comparative costings:

Some costs may not, at first, be associated with the equipment under consideration and, therefore, not be included in the costing. For example, if more space is required by one of the units under consideration, then building costs should be correctly proportional to take account of this. Other examples are when one unit requires additional services, such as electrical and water supplies and this involves additional expenditure on new or improved facilities.

The difference between one choice and another may mean a relocation of labour rather than an increase or reduction. For example, a batch freezer may need only a few minutes to load and unload the freezer and the labour requirement may be considered to be less than that required by a continuous freezer which needs constant attention. The batch freezer's main labour requirement, however, has been merely transferred to another location where trays and trolleys are loaded, and this labour cost should also be taken into consideration.

Some of the costs more readily associated with different types of equipment are often inaccurate. Example of this is that the weight lost by the product during freezing can vary between one type of freezer and another and, rightly, this should be taken into account when making a comparative costing. However, inaccurate figures are often used; usually, as the result of making unrelated comparisons, and for guidance on this subject, reference should be made to "Freezing in Fisheries".

The choice made for the period of capital depreciation can also make a considerable difference to the result of a comparative costing. A short-term costing would be in favour of a choice which had a low capital cost and high operating cost, whereas a longer period of depreciation would favour equipment with a high capital cost and low operating cost. Care should therefore be taken when making comparative costs that capital depreciation times are realistic and applicable to the

situation. It is possible, due to differences in the circumstances which relate to the choice under consideration, that different periods of depreciation can be applied to the various options.

A procedure wrongly used in comparative costing is to isolate one cost which may obviously be different between the various choices and make overall decisions based on this comparison, which may not be valid if the cost is placed in its time perspective within the total cost of the operation. Calculating the cost of changing, the operational temperature of a cold store is an example which can be used to demonstrate the effect of this type of costing. From Table 5 it can be calculated that the power requirement for operating a cold store at -30°C can be about 30% higher than for the store operating at -20°C, and this is of obvious significance to the store operator. An overall cost, however, has been made which shows that operating at -30°C is only about 4% more costly than at -20°C. When it is further considered that cold storage costs may only account for about 8% of the cost to the consumer, the increase in cost may therefore be insignificant compared to the potential benefits in terms of product quality.

Other information on costing, together with individual costings for freezing and cold storage operations, is given in "Freezing in Fisheries".

Table 74

Labour requirements

Position	Salary/ month (US$)	No.
Manager	1 125	1
Personal assistant	225	1
Shift supervisor	560	2
Clerk/cashier	337	2
Mechanic	150	2
Tally man	135	2
Reception		
Foreman	112	2
Labourers	90	10
Freezing		
Foreman	112	2
Labourers	90	26
Cold store		
Foreman	112	2
Labourers	90	10

Table 75

Capital costs

No.	Item	US$
1	Building	33 750
2	Plate freezer	22 275
3	Chillroom	9 900
4	Cold store	17 550
5	Freezer trays	2 925
6	Fish boxes	6 187
7	Ice plant	19 800
8	Ice storage bin	4 950
9	Standby generator	13 983
10	Weighing machine	675
11	Work tables	4 500
12	Steam cleaner	2 925
13	Production line items	4 950
14	Office equipment, clothing, etc.	4 950
15	Pick-up truck	2 375
	Sub-total	151 695
	10% contingency	15 169
	Total	166 864
	CIF at 20% items 2-15	23 589
	10% installation and commissioning items 2-15	11 794
	Grand total	202 247

Notes: 1 - 250 m^2 @ US$ 135/m^2

2 - 4-station mini-freezer; total charge 180 kg; 5 charges/day

3 - 10-t capacity, temperature range -1° to +1°C

4 - 20-t capacity, design temperature -30°C

5 - 30 x 2

6 - 500

7 - 2.7 t/24 h

8 - Local construction

9 - 70 kVA

10 - 100-kg flat bed

11 - 6 of each ; stainless steel top, wooden supports

12 - One, with water input, diesel powered

Table 76

Operating costs

No.	Item	US$
1	Labour	83 700
2	Power	28 125
3	Packaging	29 812
4	Water	262
5	Insurance, spares, maintenance, repairs	7 762
	Total	149 661

Notes: 1 - See Table 76
2 - 250 000 kWh @ US$ 0.1125/unit
3 - 450/day, 2-kg inners, plus 45/day of 20-kg outers
4 - 1 000 t @ US$ 0.56/1 000 litres

Calculation of the annual cash available for the purchase of raw material can be a rather involved accountancy procedure and it is beyond the scope of this document to deal with this aspect in detail, especially since procedures will also vary depending on local circumstances. The procedure used is therefore an elementary one which does not take account of the finer elements of accountancy, but it should be sufficient for an initial costing at the planning stage of a project.

	US$	US$
First cost		
Buildings and equipment (Table 75)		202 247
Annual fixed costs		
Depreciation (10%)	20 224	
Interest (10%)	20 224	
Insurance and taxes (4%)	8 089	
Capital maintenance (4%)	8 089	
	56 626	
Operating costs		
Labour, power, water, etc. (Table 76)	149 661	
Total annual charges		
Fixed	56 626	
Operating	149 661	
Total		206 287

Table 77

Derived raw material prices for the production of frozen whole prawns

Ex-plant price/kg (US$)	Annual income (US$)	Annual costs (US$)	Annual cash for raw material (US$)	Raw material requirement (t)	Derived landed price/kg (US$)
2	450 000	206 287	243 713	237	1.01
4	900 000	206 287	693 713	237	2.93
6	1 350 000	206 287	1 143 713	237	4.82
8	1 800 000	206 287	1 593 713	237	6.72

Table 78

Derived raw material prices for the production of frozen headless prawns

Ex-plant price/kg (US$)	Annual income (US$)	Annual costs (US$)	Annual cash for raw material (US$)	Raw material requirement (t)	Derived landed price/kg (US$)
3	675 000	206 287	468 713	394	1.19
6	1 350 000	206 287	1 143 713	394	2.90
9	2 025 000	206 287	1 818 713	394	4.61
12	2 700 000	206 287	2 493 713	394	6.33

The derived raw material prices in Tables 77 and 78 show the effect of variations in the ex-plant selling price for two products. Other variables, such as labour, water and power costs, can be introduced into the calculations and thereby all likely cost combinations can be explored at the planning stage.

Table 79

Enthalpy and apparent specific heat of cod flesh

Temperature (°C)	Enthalpy datum -40°C (kcal/kg)	Apparent specific heat (kcal/kg °C)
-40	0.00	0.44
-36	1.77	0.45
-32	3.60	0.47
-28	5.55	0.51
-24	7.67	0.55
-20	10.03	0.62
-16	12.69	0.72
-14	14.18	0.78
-12	15.84	0.87
-10	17.73	1.01
-8	19.99	1.27
-6	23.01	1.85
-4	28.05	3.61
-2	42.16	15.68
0	77.16	0.99
2	78.90	0.87
4	80.65	0.87
6	82.39	0.87
8	84.14	0.87
10	85.89	0.88
12	87.64	0.88
14	89.39	0.88
16	91.14	0.88
20	94.65	0.88
24	98.17	0.88
28	101.69	0.88
32	105.21	0.88
36	108.73	0.88
40	112.25	0.88

Notes: Enthalpy is the heat content of the fish measured above an arbitrary datum of -40°C. The change in enthalpy between 10°C and -30°C will therefore indicate the amount of heat that has to be removed when freezing fish.

Specific heat is the heat that has to be added or subtracted to change the temperature of the fish by 1°C. In the Table, this is listed as apparent specific heat since at temperatures below 0°C, it consists of a combination of both sensible and latent heat.

8. LITERATURE CONSULTED

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Recommended International Code of Practice for Lobsters, ALINORM 79/18, Appendix VI

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Water Supplies for Fish Processing Plants, FAO Fish.Tech.Paper No. 174

Freezing in Fisheries, FAO Fish.Tech.Paper No. 167

Refrigerated Storage in Fisheries

Road Transport of Fish and Fishery Products, FAO Fish.Tech.Paper No. 232

Support and Development of the Retail Trade in Perishable Fishery Products, FAO Fish.Tech.Paper No. 235

9. CONVERSION FACTORS

	To obtain	From	Multiply by the following
3.281	metres	feet	0.3048
10.76	square metres	square feet	0.0929
35.32	cubic metres	cubic feet	0.0283
0.22	litres	UK gallons	4.546
0.264	litres	US gallons	3.785
2.205	kilogrammes	pounds	0.454
1.016	metric ton	ton	0.984
0.00142	kilogrammes per square metre	pounds per square inch	703
3.97	kilocalories	British thermal units	0.252
1.341	kilowatts	horsepower	0.746
0.00156	kilocalories per hour	horsepower	642
0.001163	kilocalories per hour	kilowatts	860
0.0003307	kilocalories per hour	tons of refrigeration (US)	3.024
Myltiply by the above	to convert	to	

The International Systems of Units (SI Units) is now widely used and some conversions relating to the above units are given below:

Mass

1 metric ton = 1 ton = 0.984 tons (UK)

Pressure

1 kg/m^2 = 1 kgf/m^2 = 1 kp/m^2 = 9.807 Pascal (Pa) = 9.807 Newton/m^2(N/m^2)

Energy

1 cal = 4.187 Joules (J)
1 kWh = 3.6 Megajoules (MJ)
1 Btu = 1.055 kilojoules (kJ)

Power

1 hp (UK or US) = 0.746 kW = 0.746 Joules/second (J/s)
1 hp (metric) = 0.736 kW = 0.736 J/s
1 Watt (W) = 1 J/s

Heat Flow Rate

1 kcal/h = 1.163 J/s = 1.163 W
1 Btu/h = 0.293 J/s = 0.293 W